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DEVELOPMENT OF A HIGH ALTITUDE LOW OPENING HUMANITARIAN AIRDROP SYSTEM

**by
Marc N. Tardiff**

July 2017

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October 2010 – July 2015**

Approved for public release; distribution is unlimited

**U.S. Army Natick Soldier Research, Development and Engineering Center
Natick, Massachusetts 01760-5000**

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Preface

This work was performed by the Airdrop Technology Team of the Aerial Delivery Directorate at the U.S. Army Natick Soldier Research, Development and Engineering Center (NSRDEC) in partnership with the Office of the Secretary of Defense, United States Transportation Command (USTRANSCOM) and the United States Air Force Air Mobility Command during the period of October 2010 to July 2015. The goal of the program was two-fold: (1) provide a rapid humanitarian aid response capability for the first days after a disaster, and (2) aurally deliver food and water directly onto a population. This effort involved research into the injury thresholds of free-falling aid items, the design of a delivery system (airdrop and helicopter sling load), and development of both an analytical model to characterize deployed aid item dispersion and a strategic logistic planning and cost assessment tool for humanitarian operations.

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DEVELOPMENT OF A HIGH ALTITUDE LOW OPENING HUMANITARIAN AIRDROP SYSTEM

1 Introduction

Disasters, both natural and man-made, occur every year and can significantly impact a population near the disaster site. Large disasters, like the Fukushima Daiichi nuclear leak in 2011, or smaller incidents such as the Yazidi refugees trapped on Mount Sinjar in northern Iraq in 2014, can leave a population without the basic necessities of life. In these situations, individuals, groups and nations join together to provide food, water, clothing, shelter, and medical supplies. In some disasters, ground lines of communication and transportation may be damaged or destroyed, making it impossible to quickly deliver aid via traditional ground methods. By contrast, aerial delivery can provide humanitarian aid response within hours following a disaster and into locations where damaged infrastructure makes other modes of transportation and delivery impossible.

Aerial delivery of humanitarian aid by the U.S. Army and its armed services partners is currently performed by one of three methods: the container delivery system (CDS), variations of the CDS system using smaller components, or the Tri-Wall Airdrop System (TRIADS). The CDS methods can deliver food in the form of Meals, Ready-to-Eat (MREs) or Humanitarian Daily Rations (HDR), bottled water and other supplies between 501-2,200-lb in mass quantities. It utilizes an A-22 cargo container and a 64-ft diameter parachute (G-12 canopy) to deliver the items. The canopy deploys and the payload falls to the ground at a constant descent rate of about 24-ft/s. There are multiple variations of the CDS method that utilize smaller containers, smaller parachutes and smaller payloads but have similar characteristics to the CDS method. A TRIADS box is restricted to only MREs and/or HDRs between 747-1375 total pounds depending on deployment altitude. TRIADS is a large cardboard box that is loaded into the aircraft and rips apart upon exit, allowing the MREs/HDRs to disperse and free fall to the ground.

The currently utilized solutions present significant risk of injury to the receiving population from the descending items. The primary concern of CDS payloads and free-falling MREs/HDRs are that they can land with enough force to severely injure ground personnel and thus are required to have a drop zone free of buildings and people. Delivering a substantial volume of aid in a single container also raises secondary concerns, such as a weapon-wielding segment of the population taking control of the container and rationing out the aid as they see fit.

The Aerial Delivery Directorate (ADD) at the U.S. Army Natick Soldier Research, Development and Engineering Center (NSRDEC), in cooperation with U.S. Air Force (USAF) Air Mobility Command (AMC), U.S. Transportation Command (USTRANSCOM), the Office of the Secretary of Defense (OSD) and other partners, have developed a humanitarian airdrop capability that will allow aid to be dropped directly over a population in need, while significantly reducing or eliminating the risk of human injury. The program was called Humanitarian Operations Packaged Essentials (HOPE), and work was performed from October 2010 to July 2015. The goals are to deliver food and water to a population, reduce the risk of injury from

falling aid items, and disperse the aid items throughout the population while minimizing the logistical burden on the Air Force.

This program was divided into three main phases: the development of safe aid items, the engineering of the delivery system, and the production of the software to plan the humanitarian assistance mission. The safe delivery items were primarily developed at NSRDEC with input from the United States Army Aeromedical Research Laboratory (USAARL), L-3/Jaycor and Georgia Technical Institute. The Combat Feeding Directorate (CFD), in conjunction with the ADD, used the test data from USAARL to develop packaging that would deliver the aid items to the ground safely and significantly reduce the probability of human injury due to aid item impact. The delivery system development was conducted by the ADD and utilized the data from USAARL. The developed system utilizes fielded airdrop components in addition to impact attenuation components to bring the impact forces within the limits identified by USAARL. The mission planning software associated with item dispersion modeling was conducted by Charles Stark Draper Laboratory under contract with NSRDEC and funded by the Air Force Research Laboratory (AFRL) and NSRDEC. Draper analyzed the data from NSRDEC drop tests and developed an algorithm that predicted the aid item ground dispersion footprint given various airdrop parameters. Information associated with the humanitarian response network was used by the Army Research Laboratory (ARL) to develop a strategic planning tool that will help decision makers understand the trade-offs when conducting a humanitarian airdrop mission.

2 Aid Item Development

To use the TRIADS system, military personnel are required to maintain a drop zone free of people until the MREs/HDRs are all on the ground. This procedure is used because of the potential for injury from a free-falling MRE/HDR. The HOPE payloads are intended to be deployed over populations and therefore have a greater probability of contacting a person. Using MREs/HDRs in the HOPE system would increase the potential for injury due to the ration weight. New aid items need to be identified and packaged to reduce injury.

2.1 Human Impact Study

Prior to developing a new humanitarian delivery system, human impact limitations needed to be identified. L-3/Jaycor, through the USAARL, conducted a study [1] that focused on the impact limits of an MRE on various body parts, theoretical ideal cushioning, and a validated closed form simulator of a foam-attenuated impact of a mass.

According to the study, “The most vulnerable parts of the body to an overhead impact are the head and neck”. Therefore, L-3/Jaycor looked to the automotive industry and its limitations for head injuries. The acceptable limits for car crashes with regards to head and neck injuries are reference values in terms of force applied to or the acceleration of the head. Table 1 displays the critical values identified in the report. The maximum force for a “Neck Injury from Shear” has a maximum load of 3100-N, which became the target maximum acceptable force for this project.

Table 1: Federal Motor Vehicle Safety Standards Reference Values

Injury Mode	Criteria	Reference Value	Equivalent Peak Impact
Skull Fracture	The FMVSS uses the Head Injury Criterion (HIC) which is a combination of average head acceleration and duration. The HIC has been shown to be accurate for only a narrow range of impact durations. A biomechanically based Skull Fracture Criteria (SFC) has been developed that has greater accuracy at short duration impacts.	$a = 124 \text{ G}$	$F_{\max} = 5500\text{N}$
Concussion	Brain injury is still a subject of intense research and no universally accepted criterion exists. For very long impact durations seen in football collisions (~15 ms) the NFL has adopted a peak acceleration of 98 G—average acceleration of 49 G. Sub-human primate studies (Japanese Automotive Research Institute) done for more realistic short duration loadings suggest average accelerations of 200 G or more. These values are higher than the skull fracture criteria because they apply to accelerations not caused by hard impacts.	$a = 200 \text{ G}$	$F_{\max} = 8800\text{N}$
Neck Injury (Compression)	Impacts from above will primarily lead to compression of the neck.	$F_{\max} = 4000\text{N}$	$F_{\max} = 4000\text{N}$
Neck Injury (Shear)	Theoretically, a person looking straight up or down could receive an impact perpendicular to the neck and induce this mode of injury	$F_{\max} = 3100\text{N}$	$F_{\max} = 3100\text{N}$
Facial bones	Small projectiles can break facial bones. The FMVSS does not consider these kinds of injuries so there are no standard reference values. The FOCUS head form measures the forces to individual facial areas and has there are suggested tolerances. The most vulnerable areas (nose, eye) have small areas so their tolerances would have to be adjusted upward to be comparable to the scale of the current analysis.	F_{\max} Cheek=1000N Nose=100N Jaw=400N Eye=70N	TBD

*Values are reference from L-3/Jaycor Report [1]

Once the maximum impact force was identified, L-3/Jaycor evaluated the TRIADS case with MREs. Their calculations had shown an MRE would impact at about 65.5-ft/s, exceeding the maximum acceptable force (i.e., 3100-N). They further evaluated this case, attempting to identify the thickness of “ideal” cushioning. Their calculations show that an MRE would need about 2.6-in of ideal cushioning to stay below the maximum impact force. Cushioning all sides of the MRE with a sufficient depth of foam would only allow for a significantly limited number of items to be delivered from each aid container. This volumetric issue eliminated the MRE from being a viable aerial delivery option for this program. An alternative aid item needed to be identified in order to not exceed the maximum impact force.

2.2 Aid Item Design

The ADD and the CFD applied the information from the L-3/Jaycor report and began a tradeoff analysis of the aid items to determine which factors could be changed to not exceed the desired

maximum impact force of 3100-N. The factors that contribute to the impact force are the mass of the aid item, the speed at which it is falling, and the cushioning factor.

The L-3/Jaycor report showed that the weight of the MRE/HDR package significantly contributed to the excess impact forces. To reduce the impact forces, the NSRDEC team focused on identifying aid items with masses less than the 800-g MRE/HDR. Representatives from CFD identified some viable food and water packets for aerial delivery that met the weight requirement for airdrop and caloric requirement for the intended recipient. Some of these items were currently within the Department of Defense (DoD) inventory and others were commercial off the shelf (COTS) items. Table 2 shows the best candidates from the search. The Rice Bar (A28) and Wheat Bar (A29), approved by the United States Agency for International Development (USAID) [2], are wrapped in a polyolefin shrink wrap and packaged in bricks of nine bars inside a white, tri-laminate pouch. Together, the brick of nine bars weighs about 500-g, which is too heavy to meet the impact force requirements. In order to further reduce weight, CFD broke the nine bar blocks and repackaged each individual bar using a vacuum sealed tri-laminate overlay (Figure 1). Even with the reduction in weight, the impact force was still greater than the maximum force of 3100-N.

Table 2: List of Evaluated Aid Items

Item	Approximate Weight (g)
Water Packet (8960-01-124-4543)	125
Emergency Food, A28 Rice Bar-24-9	55
Emergency Food, A29 Wheat Bar-24-9	55
Emergency Food, A20 Paste Pouch-18-9	50

The NSRDEC team evaluated the packaging of each item from Table 2 in an attempt to increase the drag of the falling object, thereby decreasing the impact velocity of that item. Prior government designs and research were evaluated for suitability. One such document, which documented six different design concepts, was identified [3]. Each of these concepts utilized additional packaging material to create a parachute-like decelerator. These items would have to be incorporated into the design and installed during the manufacture of each item. The team determined that utilizing the parachute-like concepts would increase the item cost and logistic costs of the humanitarian mission. Using the additional material would generate an aerial-delivery-specific humanitarian aid item or would increase the cost of aid items even if they were to be delivered in a more traditional method. For these reasons, the team decided to explore increasing packaging surface area and aerodynamic drag.

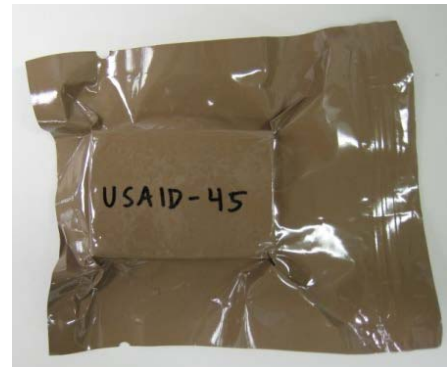


Figure 1: Prototype HOPE Aid Item

Members of ADD calculated the required drag area of the USAID bars to be 25-in² to ensure that the velocity at impact would be less than 26-ft/s. CFD then packaged Rice Bars into the vacuum sealed tri-laminate pouch, ensuring the surface was 25-in². Once the bars were assembled, it was

observed that the tri-laminate overlay had some sharp corners and edges that could be harmful if the edge/corner contacted someone at the impact speed. The team decided to create additional samples of the Rice Bar, packaged with a foam overlay.

2.3 Aid Item Testing

Two tests were conducted during the aid item development. The first series of tests were small-scale validation drops with a limited number of data points to validate the descent rates and the impact forces. These tests were conducted at NSRDEC and were iterative during the aid item design phase. The second series of tests were conducted by L-3/Jaycor in their laboratory to verify the data collected at NSRDEC. These tests were conducted in a controlled environment with multiple samples to gather accurate descent rate and impact force data.

2.3.1 12 October 2010

On 12 October 2010, the ADD and the CFD conducted a validation test of the single bar HOPE aid item [4]. This test event was conducted to validate the calculated aerodynamic drag coefficient of the selected USAID bar packages. Individually packaged USAID bars (shown previously in Figure 1) were dropped from 31.5-ft (Figure 2). The last 5-ft were recorded using a high-speed video camera recording at 300 frames-per-second. To assist with the velocity calculations, two 18-in calibration bars were placed on each side of the target zone. The calibration bars were painted with alternating black and white strips each 1 in wide. The software package ImageJ was used to identify the distance traveled between frames, and a MatLab script utilized known inputs in order to calculate the drag coefficient for each test.

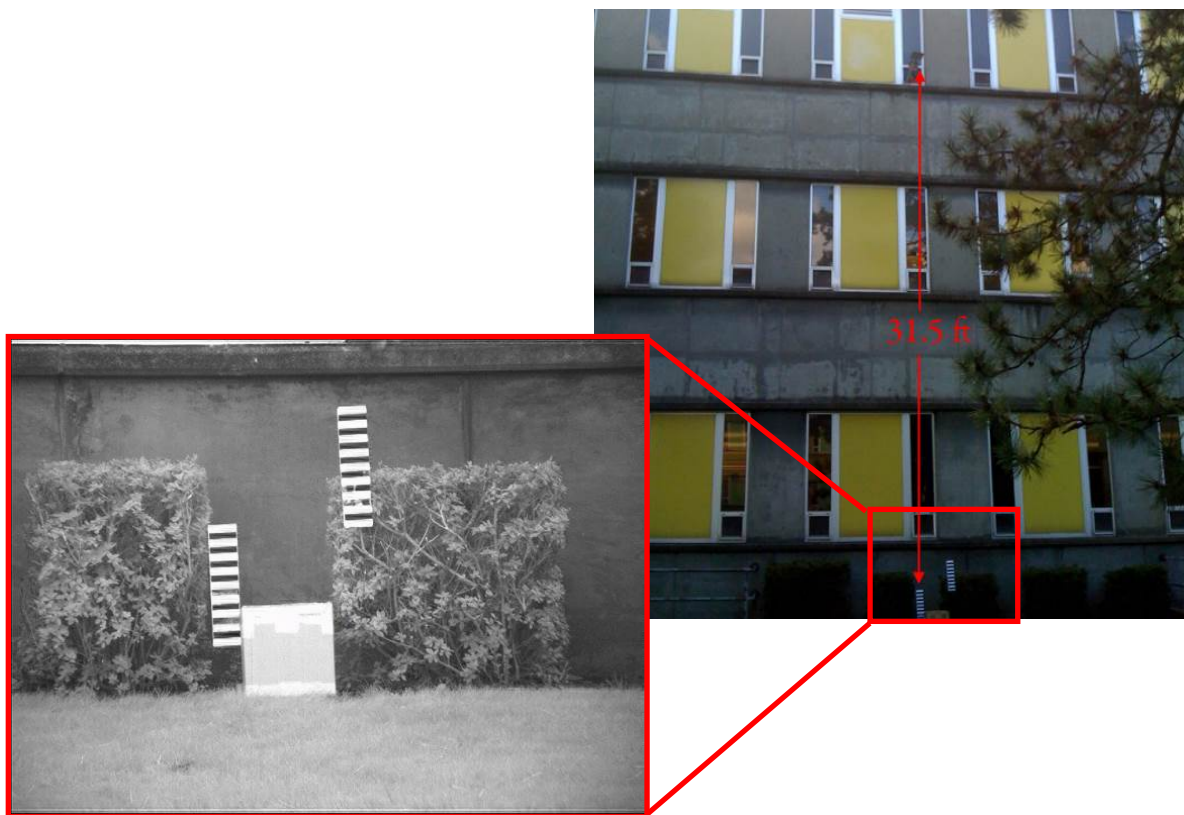


Figure 2: 12 October 2010 Aid Item Verification Test Set-up

The packets were manufactured using identical methods, yet two of the items fell completely flat and two had auto-rotating characteristics. Of the six items dropped, two landed in the bushes near the target, thereby reducing the number of usable data points. It is believed that the variation in fall characteristics was caused by the random folding of the packaging material (to include the location of the bar), which could also occur in a real-world application during packaging, storage, transport, or airdrop. Table 3 shows the recorded and calculated test data. Drops 3 and 5 have only two data sets because those packets landed in the bushes. The auto-rotating payloads (Drops 1 and 6) descended slower than their flat counterparts. Both configurations fell slow enough such that the peak impact forces were estimated to be well within acceptable limits, ranging between 611-N and 789-N.

Table 3: Test Data from 12 October 2010 USAID Bar Drop Test

Drop No.	Frames Covered	Distance Traveled (ft)	Velocity (ft/s)	C_D	Terminal ¹ Velocity (ft/s)	Peak Impact Force (N)
1	10	10.79	26.98	0.80	27.88	739.39
	20	22.24	27.80	0.73	29.09	771.52
	30	32.56	27.13	0.79	28.06	744.07
	35	37.48	26.77	0.81	27.69	734.34
2	10	11.32	28.08	0.72	29.42	780.09
	20	22.37	27.96	0.72	29.28	776.30
	30	33.30	27.75	0.75	28.72	761.69
3	10	9.57	23.93	1.06	24.22	642.34
	20	19.22	24.03	1.05	24.33	645.10
4	10	11.29	28.23	0.71	29.54	783.38
	20	22.73	28.41	0.70	29.75	788.95
	30	33.39	27.83	0.73	29.13	772.57
	40	44.83	28.02	0.72	29.34	777.92
5	10	10.36	25.90	0.88	29.52	703.25
	15	14.98	24.97	0.96	25.43	674.40
6	10	10.26	25.65	0.90	26.28	696.95
	20	19.29	24.11	1.04	24.43	647.89
	35	32.02	22.87	1.16	23.07	611.82

2.3.2 02 December 2010

On 02 December 2010, ADD and CFD conducted a validation test of single and grouped HOPE aid items. This test event was conducted to validate the aid item descent velocity and impact force of selected USAID bar and water packages.

¹ The altitude of 31.5 ft was not sufficient for the payloads to reach terminal velocity; however, the MatLab script accounted for the difference in the outputs.

The aid items selected for this test event were the USAID bars and water packet with various packaging configurations. The USAID bars used were packaged in the tri-laminate overlay. Test Sample 1 used only the tri-laminate overlay, while Test Sample 2 placed the USAID bars in the tri-laminate overlay into a 7x6 in foam pouch (Figure 3). Sample 1 was dropped in the single item configuration, four item configuration, and eight item configuration. Sample 2 was dropped only in the single item configuration. The water packets, as seen in Figure 4, were also wrapped similar to the USAID bars. Test Sample 3 used water in the tri-laminate overlay and was dropped in a three item configuration. Test Sample 4 used water in the foam pouch and was also dropped in the three item configuration.



Figure 3: USAID Items for Test Event (02 December 2010)

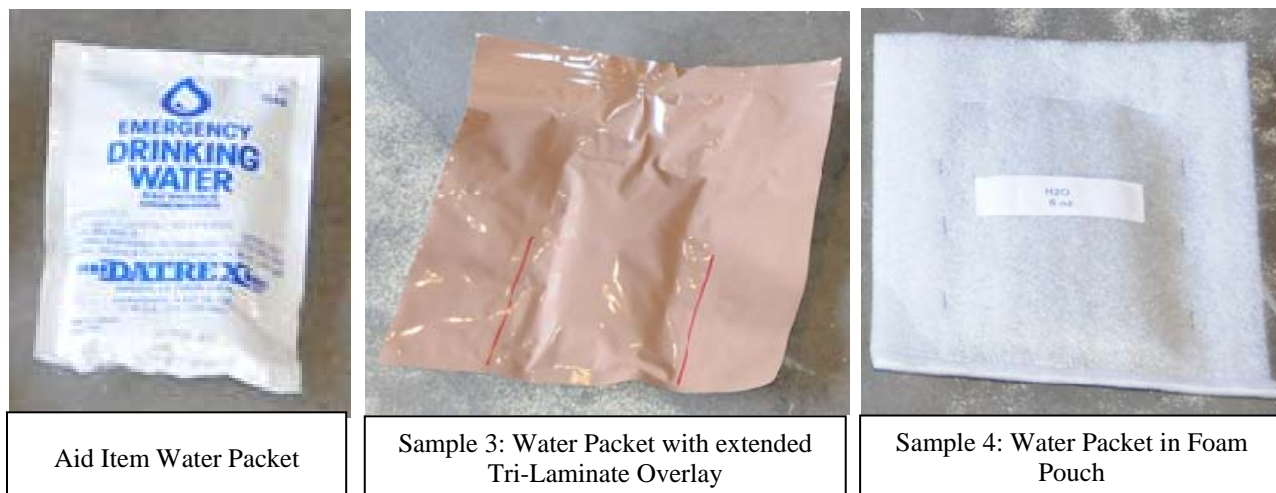


Figure 4: Water Packet Items for Test Event (02 December 2010)

The test setup consisted of a payload release mechanism secured to a pulley system via a suspension harness attached to the four corners (Figure 5). The pulley system was secured to a hard point near the ceiling (about 45-ft) that would allow the payload release mechanism to be lowered, reset, and refilled between test events. A remote control actuator that controlled the opening event was secured to the side of the payload release mechanism. The actuator was used because a release line could apply a lateral force, thereby moving the payload release mechanism off target.

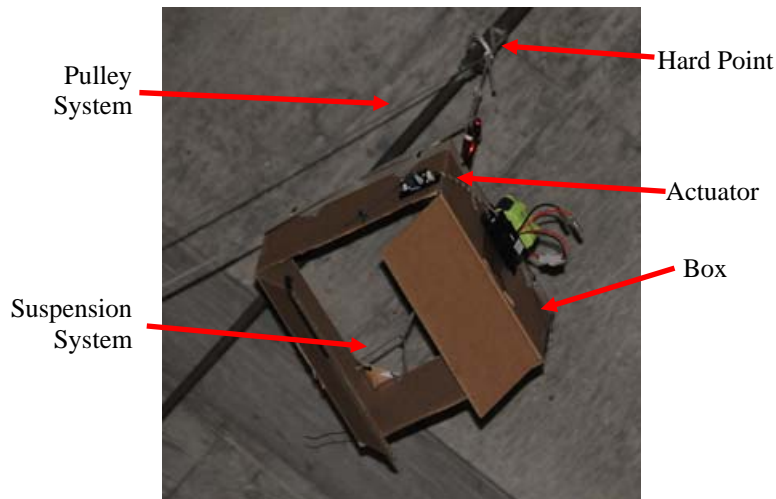


Figure 5: Payload Release Mechanism (02 December 2010)

The target for the test was a force plate located on the floor beneath the payload release mechanism (Figure 6). The intent was for the force plate to record the impact forces of each item. A high-speed video camera recording at 300 frames-per-second recorded the last 5-ft of descent and was used to calculate the descent velocity. To assist with the velocity calculations, a 60-in calibration panel was placed behind the target zone. The calibration panel was painted with alternating black and white strips each 1-in wide. The ImageJ software package was used to identify the distance traveled between frames and a MatLab script was used to calculate the velocities of each aid item.

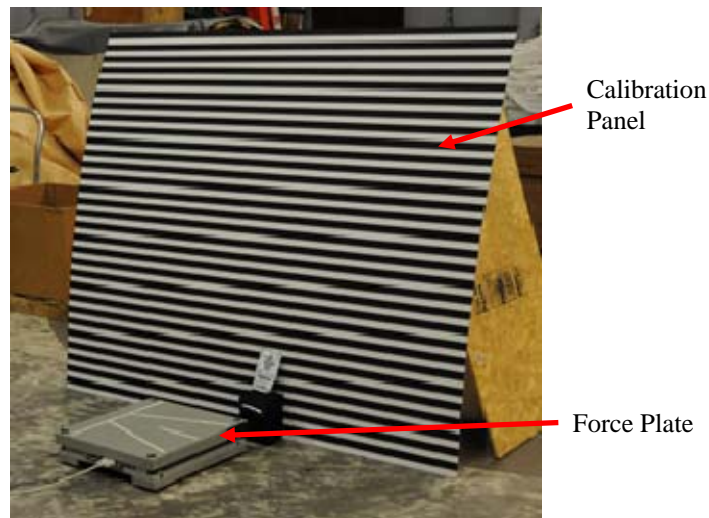


Figure 6: Force Plate Position (02 December 2010)

The aid items fluttered to the ground after activation of the payload release mechanism. Most of the items did not contact the force plate; however, those that did contact the force plate had impact forces between 650-1000-N. Table 4 has the average descent rates of the items tested. When Sample 1 was tested the first time, the item would start with an edge facing downward. The sample would accelerate until a few inches above the force plate, where the item would

make a quick turn and change direction. Samples 3 and 4 were filled with water packets that weighed 125-g. It is assumed that the flexibility of the foam packaging used in Test 6 attributed to the slower descent rate for those samples.

Table 4: Aid Item Descent Rate (02 December 2010)

Test No.	Sample No.	Items per drop	No. of Drops	Average Descent Rate (ft/s)
1	Sample 1	1	5	31.82
2	Sample 1	4	5	21.04
3	Sample 1	8	8	22.83
4	Sample 2	1	20	18.93
5	Sample 3	3	9	33.30
6	Sample 4	3	9	26.34

2.3.3 USAARL Aid Item Safety Evaluation

NSRDEC selected the four samples of aid item packaging examined in the 02 December 2010 tests (shown previously in Figure 3 and Figure 4) to have USAARL conduct airdrop verification testing. L-3/Jaycor, through USAARL, conducted the drop tests from a height of about 30-ft and recorded the impact forces of the items [5]. The drop tests were conducted to verify the data recorded at NSRDEC.

L-3/Jaycor conducted drop tests both within their laboratory and from the roof of their building, which is about 30-ft tall. High-speed video was used to record the test and to calculate the impact velocity of each test. A 14-in diameter flat force plate and a 9-in diameter hemispherical force plate were used to record the impact force of the items (Figure 7).

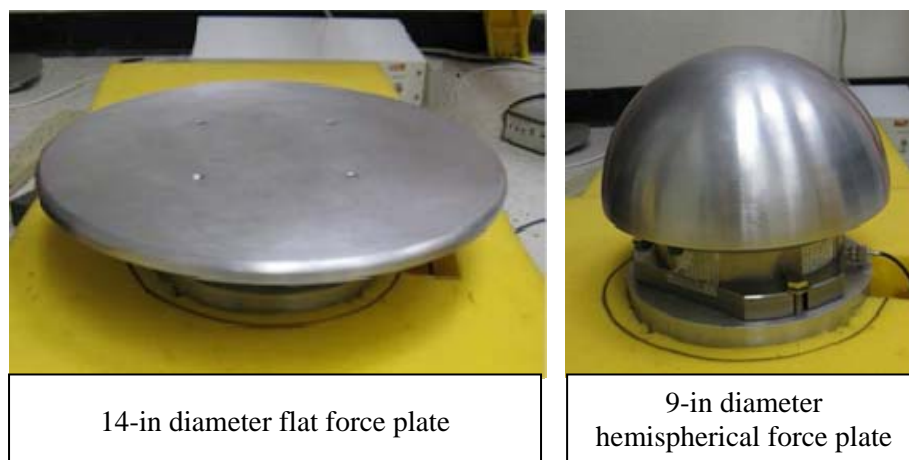


Figure 7: USAARL Force Plates

Multiple drops of each type of sample was conducted. In the case of the water packets without the laminate, seven packages ruptured on impact. The rupture occurred after the third or fourth

drop. Figure 8 shows the peak impact force in relation to the descent velocity for each sample tested. The peak force of each tested sample was below the maximum impact force for injury.

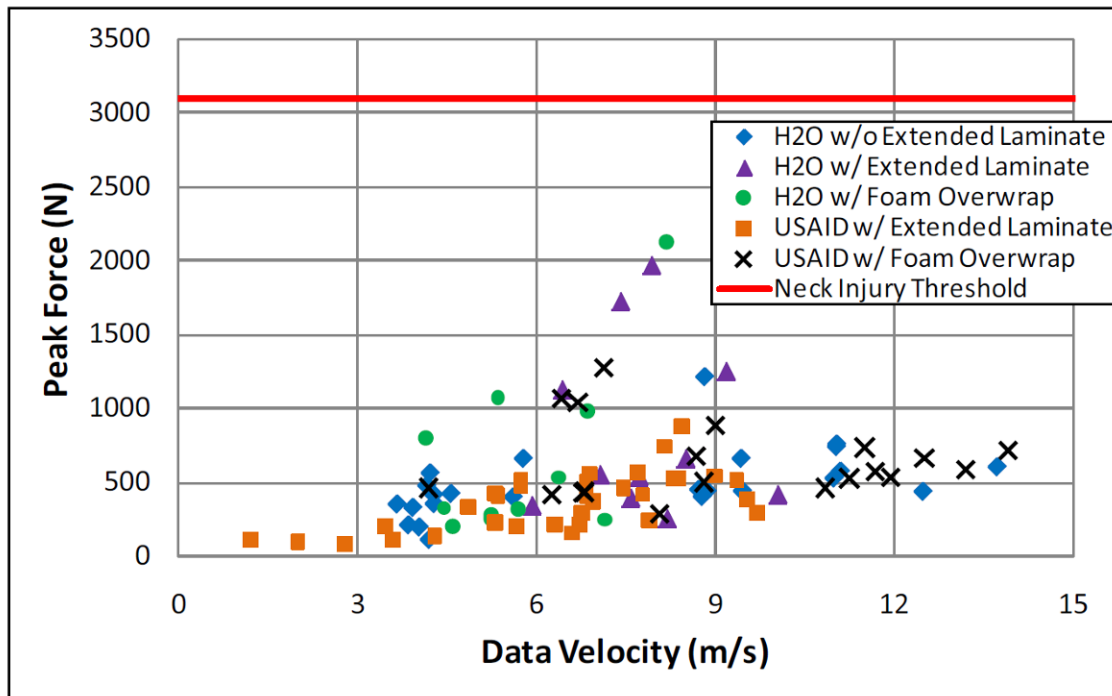


Figure 8: Impact Force for All Samples Plotted Against Drop Velocity

*Values are reference from L-3/Jaycor Report [5]

Figure 9 shows the same data plotting the item velocity with respect to the mass of the item. This plot shows the extended packaging in the form of the tri-laminate and the foam pouch increases the drag and reduces the descent velocity.

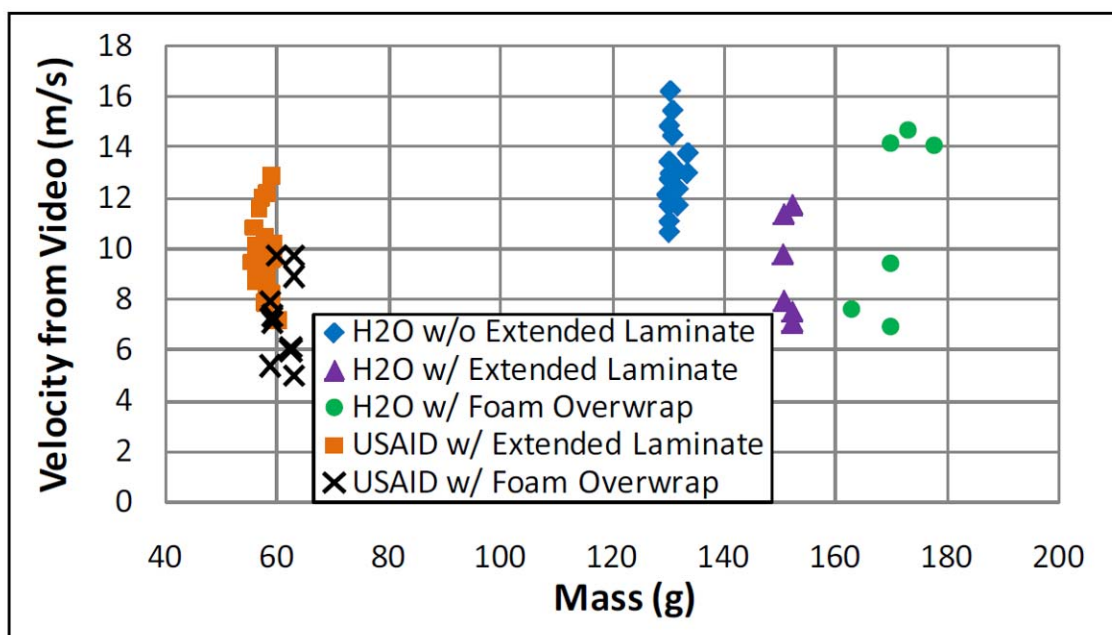


Figure 9: Impact Velocities of Drop Test Performed from the Roof (~30feet)

*Values are reference from L-3/Jaycor Report [5]

2.3.4 USAARL Accelerated Impact Test

USAARL conducted accelerated impact tests of NSRDEC-selected aid items using an instrumented mannequin head to determine impact characteristics. The aid items were accelerated into the mannequin head and the peak loads were recorded. These values were compared to the published values for various facial injuries.

NSRDEC selected the four samples of aid item packaging examined in the 02 December 2010 tests (shown previously in Figure 3 and Figure 4). These items were placed into the USAARL accelerated impact test apparatus. This test used pressure to accelerate the item to the desired velocity of 35-ft/s and targeted the item to impact the instrumented mannequin head. The intended impact point was the right eye on the FOCUS head form.



Figure 10: USAARL Accelerated Impact Test Set-up

The accelerated impact test apparatus, seen in Figure 10, consists of a compressed air reservoir and a 36-in acceleration chamber. The aid items were placed into the acceleration chamber and the air valve was opened, allowing the compressed air from the reservoir to escape through the acceleration chamber and propelling the aid item into the impact chamber.

The instrumented mannequin head, seen in Figure 11, is a system of load cells formed into the shape of a human skull and covered with a rubber-like material. When the aid item contacted the head, the force was transferred to the load cells and the values were recorded. These values were compared to published test data for head injuries.



Figure 11: Instrumented Mannequin Head

For each impact test, data were collected to investigate the risk of the fracture of the frontal bone, maxilla, zygoma, and nasal bone; eye injuries such as hyphema, lens dislocation, retinal damage, and globe rupture; and other concerns such as brain injury, skull fracture, and neck injury. Frederick Brozoski from USAARL documented the test findings [6]. Brozoski stated that “the biomechanical loads measured during an un-packaged (non-foam wrapped) USAID bar impact at approximately 32-ft/s showed the highest risk of injury was to the frontal bone.” He noted that there was a 5% risk of frontal bone fracture and a less than 5% chance of other injuries. The impacts of the foam-covered USAID bars, under the same conditions, had less than a 1% chance of injury. It was shown that both versions of the water packets have less than a 1% chance of injury. The water packet with extended tri-laminate overlay had slightly less chance of injury than the foam covered packages [7].

2.4 Final Aid Item Configuration Determination

After reviewing all the data from the aid item testing, the final configuration for the HOPE food items was determined to be the USAID bars (A28 Rice Bar and A29 Wheat Bar) wrapped in the tri-laminate and the 7x6-in foam overlay. The final configuration for the HOPE water items was determined to be the water packet (NSN 8960-01-124-4543) wrapped in the 10x10-in foam overlay. These configurations were chosen because they exceeded all requirements for injury reduction. Further, the USAID bars are currently in the US Government inventory and meet the caloric requirement for the user. The water packets are also in the US Government inventory and provide an additional capability to airdrop water into a disaster area. The low weight of the systems and the high drag numbers will ensure the aid item does not impact the ground with a force greater than 3100-N. Accelerated impact tests showed there was less than 1% chance of injury when the aid item impacted the eye area of an adult. These configurations also have a higher probability for greater dispersion because the items have a low descent rate, and winds at altitude could substantially move the items over a large area.

3 System Development

NSRDEC developed two different systems to deliver the HOPE-developed aid items. The first system was developed to be airdropped over a population from a fixed wing aircraft at altitudes from 1,000-ft above ground level (AGL) to 25,000-ft mean sea level (MSL). The second system was developed to be slung under a helicopter and released over a population with all non-aid items returning with the aircraft. Both systems utilized fielded equipment to the maximum extent possible.

3.1 Airdrop System

Using funding provided by USTRANSCOM, NSRDEC developed a humanitarian airdrop system to disperse small food and water packages directly over a population in need. The delivery system was developed to minimize the risk of injury by retaining all residual equipment with a 26-ft ring slot parachute, using a soft container to hold the aid items, and configuring the skidboard so that a foam underside cushioned any impact.

3.1.1 Preliminary System Development

The development of the airdrop system occurred in two stages: component level and system level. The system was conceptualized as a container to hold the aid items, attached to a 26-ft ring slot parachute to retain all non-aid items during the descent, and activated by the improved wireless activation device (iWAD) [8]. The system was envisioned to be deployed like a CDS payload. At a preprogrammed altitude, the iWAD activated the system, causing the parachute to invert the soft container and dump the aid items. Once the container flipped, foam moved to the underside of the skidboard to reduce potential injury to non-combatants due to impact with the residual equipment.

A feasibility test was conducted during 13-15 December 2011 at a drop zone (DZ) in Eloy, AZ. The system used a 15-ft ring slot parachute, a timing device (iWAD), a polypropylene bag containing aid items, and a ¼-in-thick skidboard with foam (Figure 12). Upon deployment from the aircraft, the 15-ft ring slot deployed and stabilized the system. After a pre-set time under the parachute, which corresponds to a desired deployment altitude, the iWAD activated a four-ring release. This release opens the bag, tips it over, and disperses the aid items. The action of the four-ring release also causes two pieces of foam to flip from the top of the skidboard to the bottom, thereby providing impact cushioning.



Figure 12: HOPE Feasibility Test

Two of the seven payloads deployed properly and transitioned as intended. The items dispersed from the bag and the foam successfully transitioned to the underside of the skidboard. The other five systems each had a different malfunction, and inspection of those payloads identified appropriate material fixes. These fixes were incorporated into the test record for this event [9]. During the successful tests, it was observed that the packages had a tendency to bunch, with upwards of 20 or more packages grouping together and landing as one large mass (Figure 13). This tendency to bunch significantly increases the risk of injury to the receiving population as the increased velocity with the mass of multiple aid items exceeds the impact forces identified by the L-3/Jaycor Report [1]. At the time, it was not known if the item grouping was a function of the aid item size, shape or exterior material being used; the system design; or the dispersion altitude. The dispersion occurred under 1,000-ft AGL, and therefore the items may not have had enough time to separate.



Figure 13: Item Grouping After Ground Impact

In total, 96 payloads employing the bag concept were airdropped from various deployment heights, activation heights, and aircraft. Aid item grouping was observed after each test. The number of packages in each group decreased with increase in altitude. It was believed that the single container method enabled packets to stay together by drafting off the first aid item. The proposed solution was to separate the larger, single volume into smaller volumes and stage the aid item deployment.

The other key features of the preliminary system were evaluated for use in the next design iteration. First, the iWAD functioned as designed and was determined to be a key component of the future HOPE delivery system. Second, the layer of foam, moved to the underside of the skidboard, was not successful; however, the foam was needed to reduce the impact force of the skidboard. The foam was therefore secured to the top side of the skidboard and during activation, the skidboard would be flipped over, placing the foam at the contact point of the residual components. Third, after more than 50% of the tests, damage to the bag material was observed, and it was determined that the material was not strong enough to handle the aid item deployment. The fourth and final observation was that the 15-ft ring slot parachute did not provide enough drag to the system, after the deployment of the aid items, to ensure a non-hazardous landing of the residual components. Thus, the 26-ft ring slot parachute replaced the 15-ft ring slot parachutes for follow-on tests because the descent rate of the residuals was determined to be below the maximum allowable impact velocity.

3.1.2 Final System Configuration

The system, in its fully rigged state, closely resembles a standard CDS bundle (Figure 14) and therefore maximizes the compatibility with USAF and Allied aircraft and minimizes crew training. The elements of the system are:

- Twelve aid boxes containing food or water items
- One ¾-in thickness plywood skid board
- One 3-in layer of paper honeycomb impact attenuator
- One 8-in soft foam impact attenuator

- One low-cost container
- One activation line
- One iWAD
- One 26-ft diameter ring slot parachute
- Other various rigging materials (as required)

The system is loaded into the aircraft, the release-away static line (RASL) is attached to the anchor line cable, and the bundle is secured to the aircraft floor. Just prior to the airdrop, the securing tie is cut, allowing the bundle to exit the aircraft. The RASL pulls the parachute off the bundle and allows the drogue parachute to inflate. The system deploys similar to traditional CDS bundles with the exception that HOPE uses a 26-ft ring slot parachute and not the standard G-12 parachute. After the 26-ft ring slot canopy inflates, it stabilizes the payload and the HOPE bundle begins its descent. At a preprogrammed altitude, the iWAD activates and initiates payload transition and dispersion. The aid items and residual components descend to the ground under the 26-ft ring slot parachute.

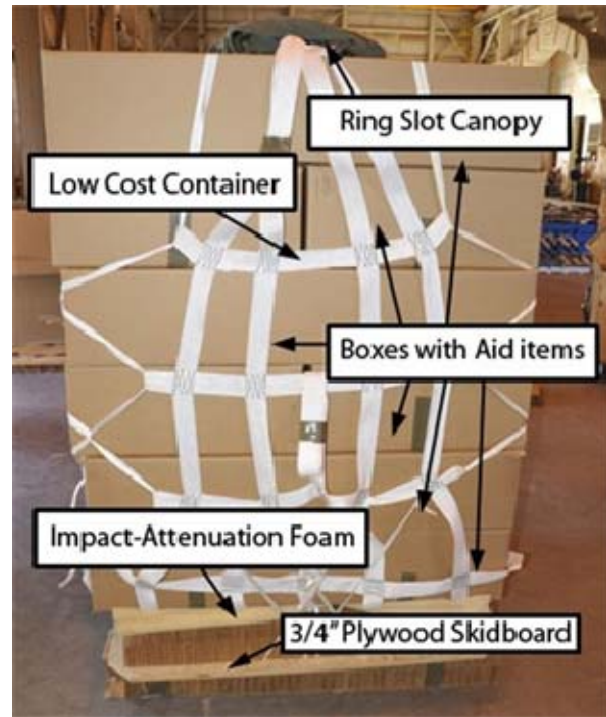


Figure 14: Fully Rigged HOPE System

The aid boxes are designed to be multi-purpose; they function as the shipping, storage, and airdrop container. The intent is to have the boxes prepackaged (with 160 food/water items, load spreader, and attachment lines attached) by the manufacturer and stored at strategic locations for humanitarian aid delivery. The boxes are received with aid items packed in the correct orientation and rigged into the HOPE system by securing the attachment lines on the aid boxes to the attachment loops on the activation line. During the rigging process, the tape sealing the boxes shut is then sliced open, which will allow the aid items to disperse once the box is inverted. Figure 15 shows the aid items in the correct orientation with the box stiffeners in place. The stiffeners compartmentalize the aid items and provide structure to the center of the box, which allows for a HOPE system to be rigged for months prior to use without any box damage due to payload compression.



Figure 15: Aid box filled with foam overwrapped water packages and box stiffeners

The activation line is used to initiate the release of the aid items and also retain the aid boxes, skidboard, and other residual components after system actuation. Figure 16 shows the activation line and identifies the major components. The activation line is made of 1-in tubular nylon webbing and is 64-ft long with the parachute attachment loop on one end and the skidboard attachment loop on the other. The iWAD and four loop release system are located at the top of the activation line, followed by a cut knife affixed 8-ft below. Six attachment loops are located in 8-ft increments below the cut knife, which serve to secure the aid boxes to the activation line, with two boxes attaching to each attachment point, forming release layers.

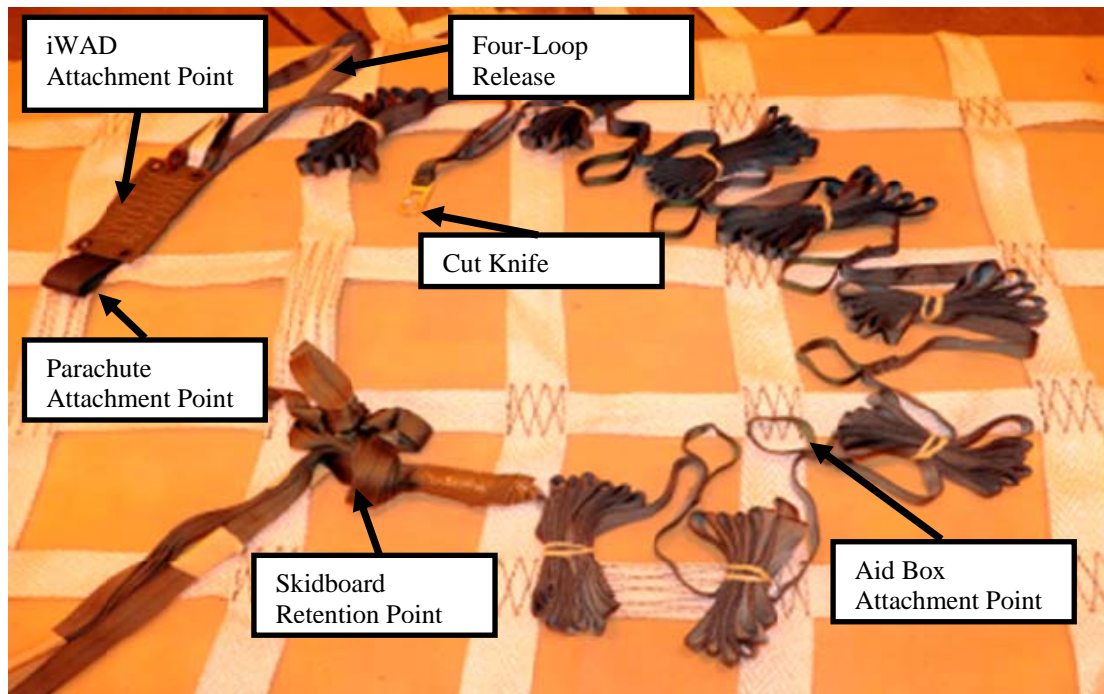


Figure 16: Activation line components

During the payload transition, the activation line cuts the closure loop, unlaces a corner of the container, separates the aid layers, deploys the aid items, retains the residual components (skidboard and empty aid boxes) through a secondary suspension system attached to the parachute, and inverts the skid board, thus orienting the foam attenuator downwards for impact. The activation line is secured to the skidboard (Figure 17) and runs between the aid boxes with the attachment line of each box secured to the activation line attachment loop.

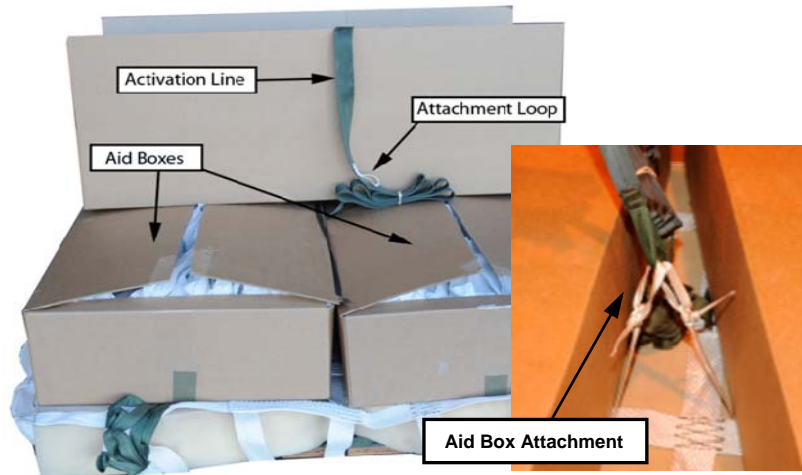


Figure 17: Rigging aid boxes, attachment loops

The iWAD (Figure 18) is programmed prior to the airdrop and can activate a spring loaded pin and/or a pyrotechnic device at a predetermined pressure altitude and/or elapsed time from when the activation pin is removed. The HOPE System utilized the pressure altitude and pin pull methods for the transition. The transition altitude decision takes into account the desired dispersion footprint and the known wind conditions. The iWAD is armed during canopy deployment via the activation lanyard attached to the parachute deployment bag. When the bag lifts off the payload, it pulls the activation lanyard and arms the iWAD. Once active, the iWAD monitors air pressure until the preprogrammed altitude is reached. At this point, the transition event begins with a retraction of the iWAD pin that holds the four ring release in place, thereby triggering payload release.

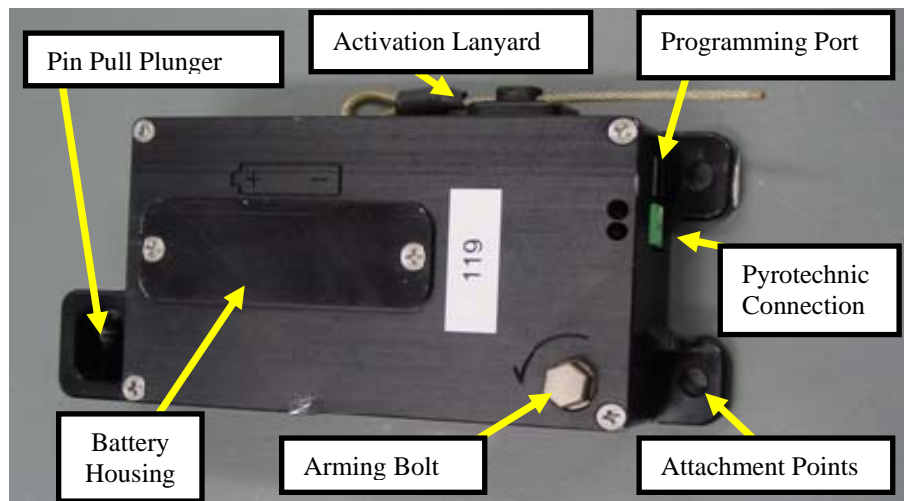


Figure 18: Improved Wireless Activation Device

3.1.2.1 Low Cost Container Rigging

The low cost container corners are traditionally secured with tied loops of ½-in tubular nylon between adjacent lateral bands (i.e., “hourglass ties”); however, the HOPE payload must be laced in a method that allows the activation line to unlatch the ½-in tubular nylon. Therefore, no solid

ties are used to secure the corners. Instead, three of the four corners use a back-and-forth lacing method where two lengths of ½-in tubular nylon are secured to the base of the low cost container and routed through the lateral band loops, crossing each other between the loops. Figure 19 shows the payload lacing concept.

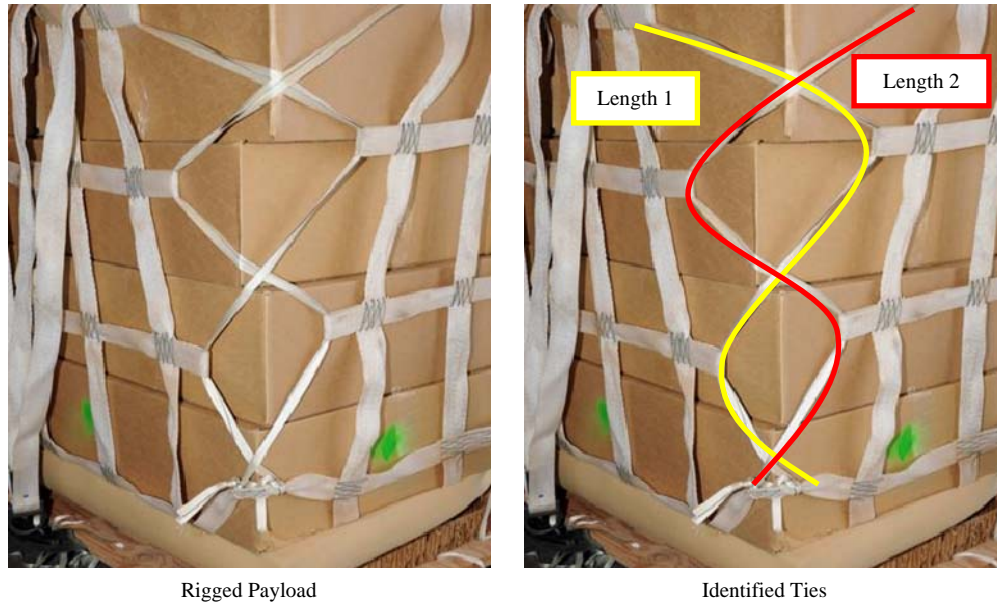
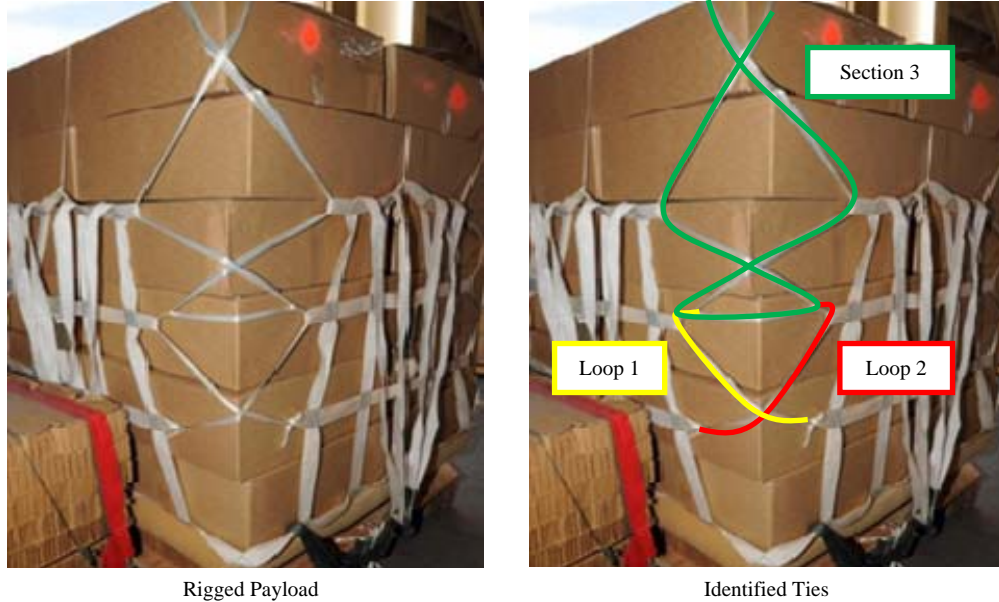


Figure 19: First three corner lacings of a fully rigged bundle

The remaining corner (fourth) uses an interlocking lacing method to ensure one corner of the container is not connected together after actuation (Figure 20). Having one corner open reduces the risk of boxes becoming snagged in the low cost container while the layers of aid boxes are being removed from the payload. This method utilizes two ½ in tubular nylon loops (identified as red and yellow lines in the figure) girth hitched to the lower lateral band loops of the low cost container and a third section of ½-in tubular nylon (identified as the green line in the figure) routed through the ends of the first two ½-in tubular nylon loops.



Rigged Payload

Identified Ties

Figure 20: Fourth corner lacings of a fully rigged bundle

The free ends of all four corner lacing loops are gathered with a closure loop. When tightened, this secures the payload together, providing vertical and lateral restraint while maintaining the integrity of the load. The loop is routed through the cut knife attached to the activation line (Figure 21). Once activated (“transitioned”) the closure loop is cut and the boxes are free to be deployed from the bundle as the payload falls from the parachute.

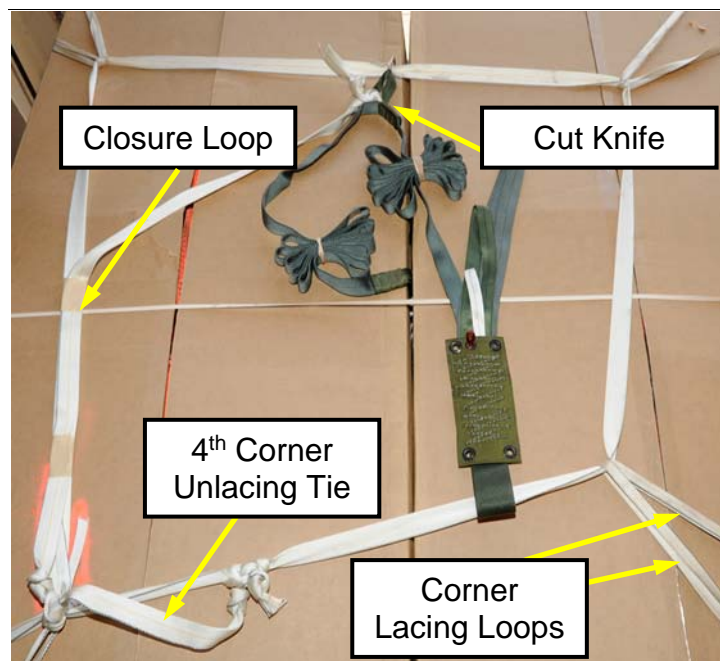


Figure 21: Termination of the corner lacing loops to the confluence ring, showing the cut knife attached to the activation line

The container is secured to the plywood skidboard using standard CDS skidboard ties of ½-in tubular nylon [10]. These provide the vertical payload restraint while the system is in the aircraft. As these are tightened, the soft foam attenuator is compressed. With a compressed initial state, the foam must have a reasonable compression set rating, as determined by ASTM D3575, to ensure that the foam will have expanded to acceptable levels prior to impact. The foam in this system has a value of 12%, indicating that it will recover all but 12% of the compressed distance after being exposed to prolonged heat and pressure.

3.1.2.2 System Transition

The system is deployed identically to traditional CDS bundles. The RASL deploys the ring-slot parachute and pulls out the iWAD activation pin. The canopy inflates, stabilizes the payload, and begins its ballistic descent. The iWAD is armed 5 s after canopy deployment and begins to monitor air pressure. Figure 22a shows the payload under the 26-ft ring slot parachute; this is the configuration of the system prior to the iWAD initiating transition. Once the pre-programmed “transition” altitude is reached, the event begins with the retraction of the iWAD pin triggering payload release. Figure 22b shows the initial phase of the transition. As the activation line becomes taut, the first layer of boxes is being lifted off the payload and the aid items are being dumped, fluttering towards the ground. After the payload separates another 8-ft from the parachute, the next layer of aid boxes is extracted. Figure 22c shows a middle stage of the transition, where four of the layers of boxes have been lifted off the payload. The process is repeated until all six layers have been removed from the low cost container. Figure 22d shows the system with all of the aid boxes flipped over and the skidboard inverted with the residual airdrop components still attached to the parachute. The aid items are developing a “cloud”. Figure 22e shows the “cloud” of air items descending faster than the residual airdrop items. The staggering of dispersing of aid items is designed to prevent clumping, where groups of aid items can stack and increase aid item descent rate, total mass, and impact force.

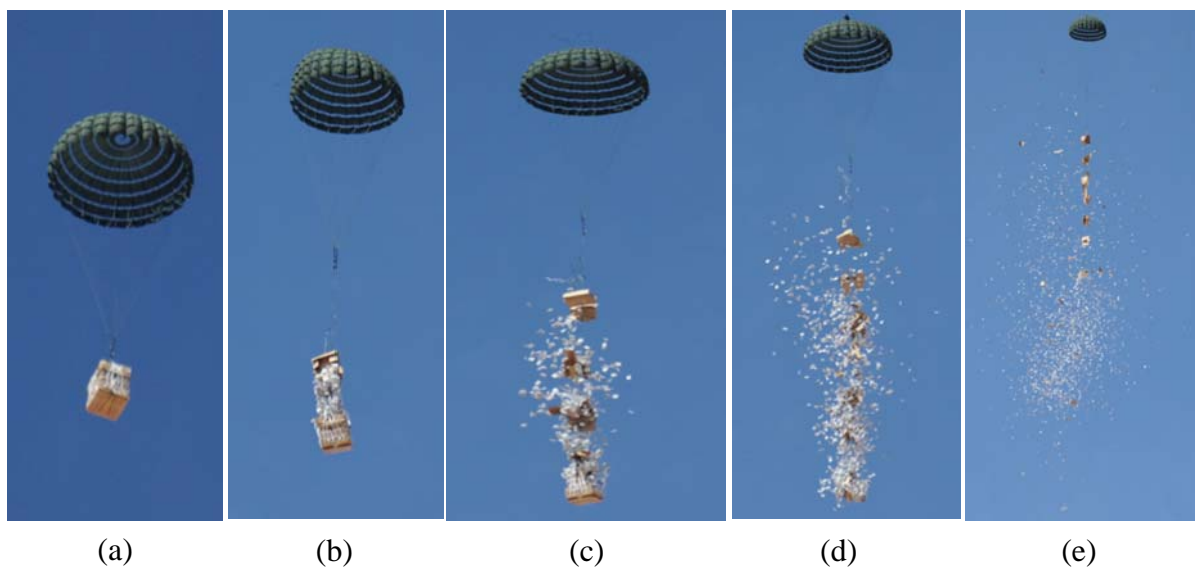


Figure 22: System Undergoing Transition

After the six layers of aid boxes have been removed from the container and their contents dispersed, the activation line inverts the plywood skid board, orienting the foam attenuator

downwards (Figure 23). The foam attenuator is secured to the skidboard via two ties of Type III nylon cord with the paper honeycomb sandwiched between the foam and skidboard. This attachment is accomplished with a secondary suspension system attached to the skid board. The slings are secured on the underside of the skid board during rigging to prevent interference with the aircraft roller systems and are routed between two sides of the low cost container.



Figure 23: Inverted skid board, foam face down, supported by the supplemental suspension system

3.1.3 System Testing

Testing was conducted at YPG and Eloy, AZ from November 2012 to March 2015 using water packets in the foam overlay and 8-in long sections of 4x4 wood blocks as a payload substitute. During this period, 113 payload test drops were conducted using the final configuration to refine system design, ensure reliability, assess survivability of the aid items, and gather dispersion data. Most of the 113 test drops consisted of a single payload on a single pass; however, there were over 20 tests where multiple payloads were released on a single pass. The final test was 10 payloads released on the same pass (2 sticks of 5 payloads each side by side). Test data for each test sequence can be found in Appendix A.

After each test, the aid items were recovered, transported to an inspection location, and inspected. The inspection included checks for ruptured foam overlays that would allow the internal contents to separate from the foam and damage to the internal packaging that would allow water to leak or would damage the vacuum seal on food items. Figure 24 shows two aid items that were identified as damaged: the lower package because the foam overlay was missing, and the upper package due to internal packaging damage that had caused water to leak out. Throughout testing, inspection results showed about an 89% survivability rate, independent of winds, “transition” altitude, and payload size. This percentage includes damage that may have been incurred during the recovery, transport, and inspection processes. During the inspection process, empty foam packages were joined with packages that did not have foam overlays to prevent double counting.



Figure 24: Damaged aid items recovered

The HOPE airdrop system reliability was about 94.7% with six payload failures. The military riggers at YPG conducted a malfunction investigation and concluded the failures were due to parachute packing errors. Of the six malfunctions, two transitioned into a high-speed descent but failed to deploy the packets. The remaining four systems had broken static lines, which failed to deploy the parachute.

3.2 Sling Load System

The NSRDEC, in conjunction with the Office of the Secretary of Defense (OSD), developed an aerial delivery capability to deliver small food and water packages directly over a population in need from the cargo hook of a helicopter or vertical take-off and landing (VTOL) aircraft. This part of the program was called Humanitarian Operations Packaged Essentials from an Underslung Load (HOPEFUL) and concentrated on the deployment of aid items from the cargo hook of the helicopter. The intent was to have the helicopter release the items while retaining the residual components and allowing the helicopter to return to base for refurbishment and reuse of the equipment. The delivery system was developed to minimize the risk of injury by retaining all residual equipment to the helicopter with a retention line, thereby removing the risk of any non-aid items causing injury. This system will provide the U.S. with a safe, immediate disaster relief response capability and also fits into the United States Marine Corp ship-to-shore mission.

3.2.1 Concept Development

The HOPEFUL system development began with a concept generation phase. A system description was generated, along with underlying assumptions and pros and cons of each varying

design. The team evaluated the concepts and chose which of them would move to the system validation phase. The validation phase consisted of crane testing to verify the assumptions and release activation methodology. The concepts were down-selected to two system types after the developmental crane tests. These two systems were then operationally tested under a helicopter.

NSRDEC's ADD and CFD generated criteria that each concept must possess to be considered for use. The criteria were:

- Deliver the HOPE-developed food and water packets
- Utilize existing equipment to the greatest extent possible
- Retain all residual components with the aircraft

Six potential concepts were developed, each with unique activation and disbursement methods. The six concepts can be found in Appendix B with the identified pros and cons of each system.

Two of the concepts were down selected to the next phase of development. The first concept (Figure 25) utilized an HSL cargo net with a liner to retain the aid items and used a Wireless Gate Release Mechanism (WGRM) and associated Master Control Station (MCS) to activate the deployment of the aid items. The four legs of the cargo net came to a confluence point and were secured to the helicopter using a multiple loop release system attached to the WGRM. A variant of this system used a linear brake to control the deployment.

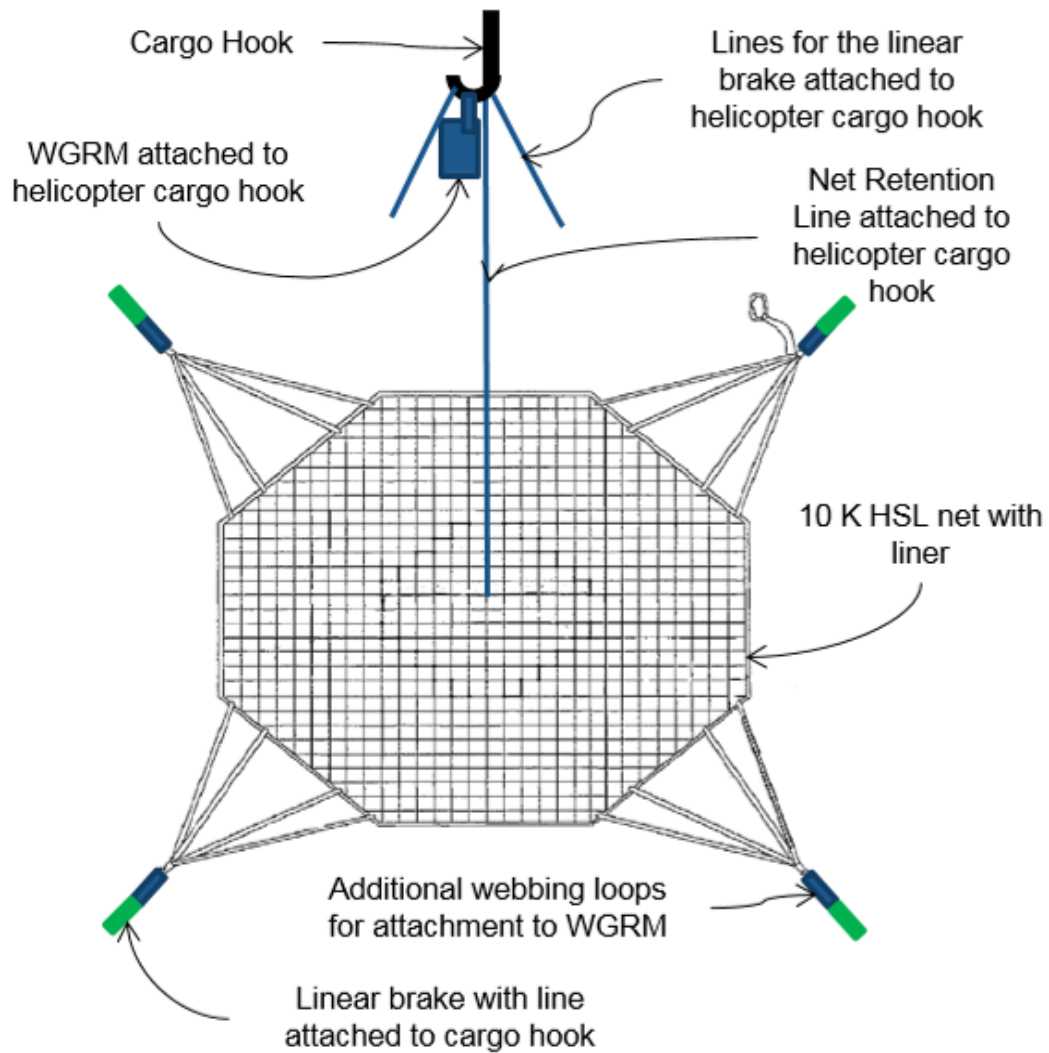


Figure 25: Sling Load Concept 1

When the system was activated, the WGRM allowed the multiple loop release to free the legs of the cargo net. Each leg fell away, allowing the contents to spill over the edge and flutter to the ground as the helicopter moved forward or remained at a hover.

The second concept was a variant of Concept 2 found in Appendix B. The system used was a helicopter firefighting water bucket (Figure 26). When activated, the aid items are allowed to pass through an orifice in the bottom of the bucket. The water bucket was attached to the aircraft via the helicopter hook with a control line attached to aircraft power. The system was activated with an aircrew-controlled button press that releases the trigger line and allows the aid items to move through the orifice in the bottom of the bucket.

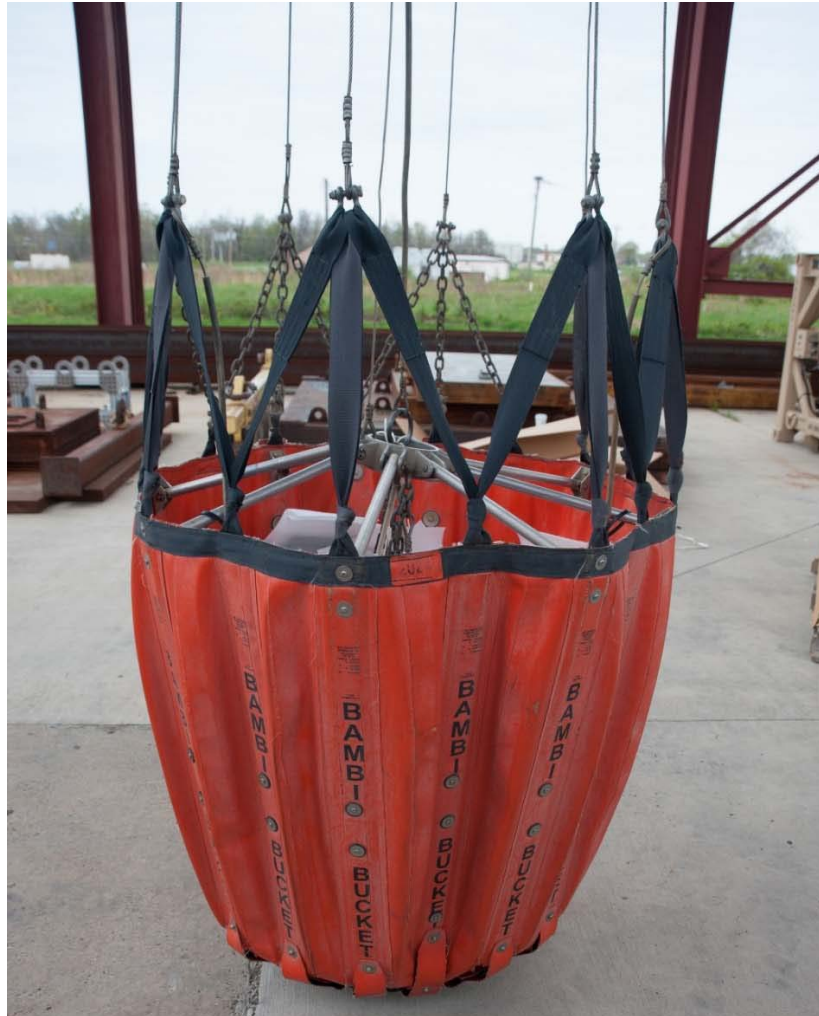


Figure 26: Sling Load Concept 2

3.2.2 Ground Testing

Ground tests of Concept 1 and Concept 2 were conducted at NSRDEC and at Aberdeen Test Center (ATC – located at Aberdeen Proving Grounds), respectively. Each concept was loaded, suspended under a crane, and activated. After each test, the configuration was modified slightly in an attempt to increase aid item dispersion or reduce system complexity.

3.2.2.1 Concept 1 Ground Testing

Ground testing of Concept 1 was conducted under the drop tower at NSRDEC. The load was rigged similarly to Figure 25 with two exceptions. First, the 10,000-lb capacity HSL cargo net was replaced with the 10,000-lb Low Cost HSL Cargo Net (LCHSLN) for ground testing. It was assumed that abrasion from the ground and shock loading over multiple test events would damage the net material of a single net. LCHSLN was used because they are disposable and cost less than the HSL cargo net. The second change was the addition of four inversion lines that connected the four legs of the cargo net to the retention line. These lines were added to reduce the chances of the metal hardware, attached to the cargo net, damaging the aircraft during flight. These lines also force the inversion of the cargo net, thereby forming a ball shape after

activation, reducing drag and loose material and therefore increasing aircraft safety. Figure 27 shows the new configuration of Concept 1 with the added inversion lines.

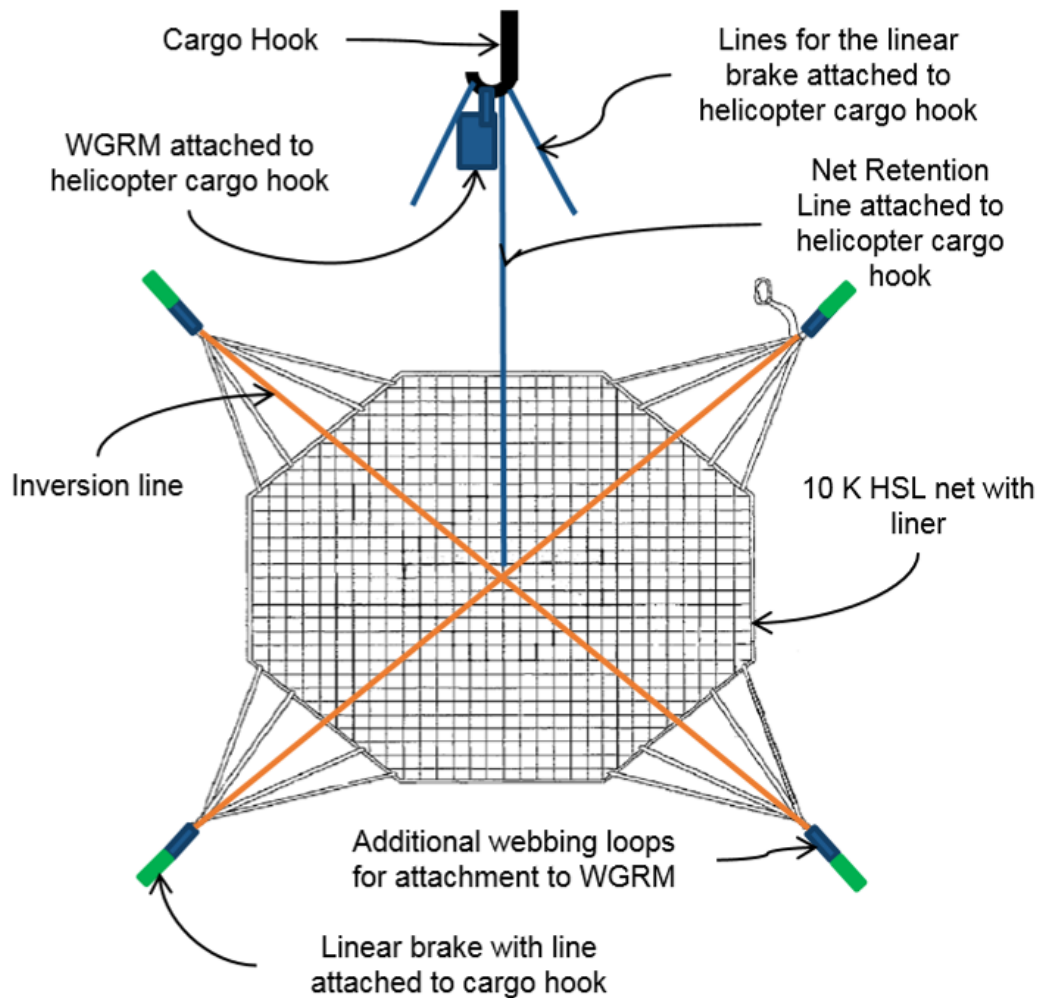


Figure 27: New Configuration of Concept 1

The modified Concept 1 configuration was placed under the crane and filled with 8-in lengths of 4x4 in wood blocks and rigged using the equipment listed in Table 5. Breakaway ties and tape were used to unitize the load as identified in TM 4-48.09 Multiservice Helicopter Sling Load: Basic Operations and Equipment [11]. Wood blocks were used in place of aid items for the initial ground test due to their increased durability.

Table 5: List of Equipment Used for NSRDEC Ground Testing of Sling Load Concept 1

	NSN	PART NUMBER	DESCRIPTION	QTY PER SET
1	4030-01-048-4044	38850-00004-046	Apex Fitting Assembly- Sling	1 ea
2	1670-01-062-6302	68F217-51	2-loop, 20 ft Airdrop Sling	1 ea
3	1670-01-602-0221	11-1-8161-1	Net, Cargo, Aerial Delivery	1 ea
			Liner	1 ea
5	8305-00-082-5752	Mil-W-5625	Webbing, nylon, tubular, 1in, 4,000 lb minimum breaking strength	4 ea
6		WA-8500-006	Wireless Gate Release	1 ea
7		WA-8000-002	MCS Kit	1 ea
8	7510-00-266-5016		Tape, adhesive, pressure-sensitive, 2-in wide roll, green	AR
9			Multi-Loop Release	1 ea
10	4020-00-240-2146		Cord, nylon, Type III, 550-lb breaking strength	AR
11	8305-00-268-2411		Webbing, cotton, 1/4-inch, 80-lb breaking strength	AR

The system was raised about 1-ft off the ground and inspected. The WGRM was powered on and synced with the MCS. The payload was lifted to maximum height (about 30-ft). Figure 28 shows the fully rigged system suspended from the maximum height of the crane. When the WGRM was activated, the multi-loop release allowed the sling legs to successfully separate and the load began its descent. The retention line caused the inversion lines to force the legs back through the bottom of the LCHSLN. The aid items then contacted the balled-up cargo net and dispersed. The final state of the system can be seen in Figure 29, which shows the LCHSLN inverted with the legs through the center of the net and the dispersion of the wood blocks.

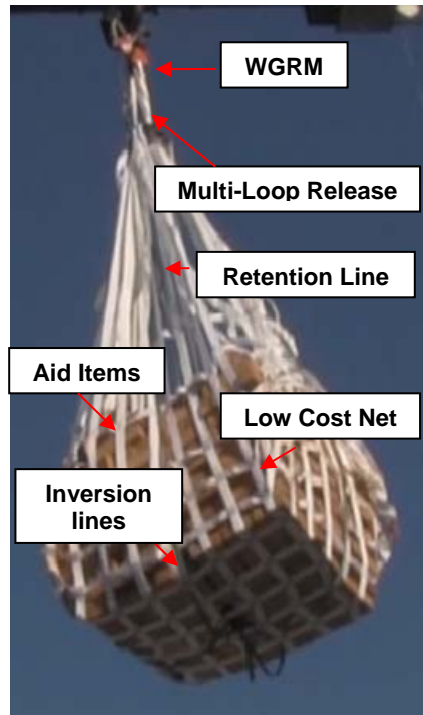


Figure 28: Fully Rigged Net



Figure 29: Final Payload Inverted Configuration

Seven drop tests were conducted from the drop tower at NSRDEC over 3 days. The first test was conducted using the initial configuration as outlined above. Subsequent tests were slightly modified to increase the wood block dispersion, which included additional ties and sections of plywood secured to different locations. The configuration of each test is outlined in Table 6. The last test used the 10,000-lb capacity HSL cargo net and the HOPE water packets to verify the system functionality would be analogous to the preceding tests with the LCHSLN and wood blocks. All plywood sections were removed from the final configuration to reduce payload drag due to the risk that a large flat surface (such as a plywood sheet) could cause additional drag and potentially force the empty net to strike the aircraft during flight.

Table 6: Net Ground Test Configurations

Drop #	Payload (lb)	Payload Items	Configuration	Results
20 November - Thursday				
H01-001	1200	Wood blocks piled in LCHSLN	Payload secured in LCHSLN. Retention line is attached to Apex and Inversion Ties. Four legs are secured to the textile multi-loop release.	Good release with minimal payload dispersion
H01-002	1200	Wood blocks piled in LCHSLN	Plywood attached to the net and payload secured in LCHSLN. Retention line is attached to Apex and Inversion Ties. Four legs are secured to the textile multi-loop release.	Good release with minimal payload dispersion.
21 November - Friday				
H01-003	1200	Wood blocks piled in LCHSLN	Same as H01-002 with plywood placed half way in payload and secured to retention line.	Good release with minimal payload dispersion. Better than H01-001
H01-004	1200	Wood blocks piled in LCHSLN	Same as H01-002 with plywood attached to the joint of the retention line and the inversion tie and payload secured in LCHSLN.	Good release with minimal payload dispersion. Better than H01-003. Plywood secured to the inversion tie broke free on activation
18 March – Wednesday				
H02-001	1200	Wood blocks piled in LCHSLN	Same as H01-001	Good release with minimal payload dispersion
H02-002	1200	Wood blocks piled in LCHSLN	Same as H01-001. Retention line was shortened to attempt better dispersion	Good release with better dispersion than H01-005
H02-003	1200	Water packets in 10,000 lb Capacity Cargo Net	Same as H01-001	Good release with minimal dispersion

3.2.2.2 Modified Concept 2 Ground Testing

Ground testing of the modified Concept 2 was conducted at ATC [12] at their Lift and Tie-Down Test Facility. The purpose of the helicopter firefighting water bucket (Figure 26) is to allow helicopters to transport water to a fire that is not easily accessible by traditional methods. The crew attaches the bucket to the cargo hook of the helicopter and a power cable into the aircraft power port, which transfers power to the release mechanism and allows the pilot or aircrew to activate the release of water in the bucket. The aircraft flies to a water source, dips the bucket into the water (filling the bucket) and transports the water to the fire. When the pilot activates the release mechanism, the weight of the water pushes the sides apart, allowing the water to flow through the central opening.

The water bucket needed to be slightly modified to allow the water packets to fall through the central opening. The release mechanism has a single line that extends to the bottom of the bucket and pulls on several lines laced through the mouth of the central opening. These laces needed to be reconfigured to allow for the larger water packets to pass through the opening. The bucket was suspended from the crane hook (similar to the helicopter hook). Figure 30 shows the system suspended from the crane. When the load was about 6-ft off the ground, the bucket was activated.

Testing started with the drop configuration H03-001. After each test, the configuration was modified and retested to maximize item dispersion and minimize system complexity. Each of the configurations and results are outlined in Table 7 and more information on each configuration is identified in Appendix C.

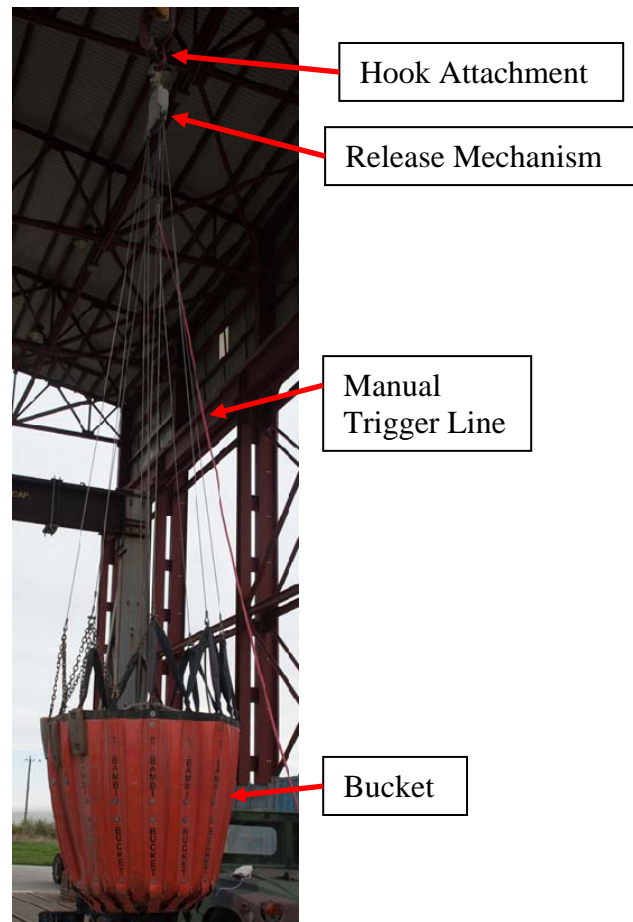


Figure 30: Fully Rigged Water Bucket

Table 7: Bucket Ground Test Configuration

Drop #	Payload (lb)	Payload Items	Configuration	Results
28 April - Tuesday				
H03-001	400	HOPE water packets	Water bucket with the opening lace configuration changed to allow the packets through	Items did not fall out of the bucket
H03-002	400	HOPE water packets	Same as H03-001 with one G-12 clevis suspended on the bladder for weight	Items did not fall out of the bucket
H03-003	400	HOPE water packets	Same as H03-001 with two G-12 clevises suspended on the bladder for weight	Items did not fall out of the bucket
H03-004	400	HOPE water packets	Same as H03-001 with three G-12 clevises suspended on the bladder for weight	Items did not fall out of the bucket
H03-005	300	HOPE water packets	Same as H03-004 with a cardboard funnel inserted into the bucket to guide the packets to the center of the bladder and a plywood trap door	Some packets fell out, but most were stuck in the bladder
H03-006	250	HOPE water packets	Same as H03-004 with a polyvinyl tube inserted into the bucket to guide the packets to the center of the bladder and a plywood trap door	More packets than H03-004 fell but most were still stuck in the bladder

The final configuration utilized the helicopter water bucket with a few modifications. The bladder was fully extended and a section of 1-in tubular nylon webbing was added to the end of the activation line to accommodate the increased length in the system. A polyvinyl liner was inserted into the bucket, extended into the bladder, and secured with three evenly-spaced ties. The liner was used to reduce the friction between the foam and the rubber container. The activation line was attached to the plywood board, which served as a trap door for the aid items in the bucket. Figure 31 shows the exterior of the bucket with the bladder fully extended, while Figure 32 shows the interior of the bucket with the liner in place.

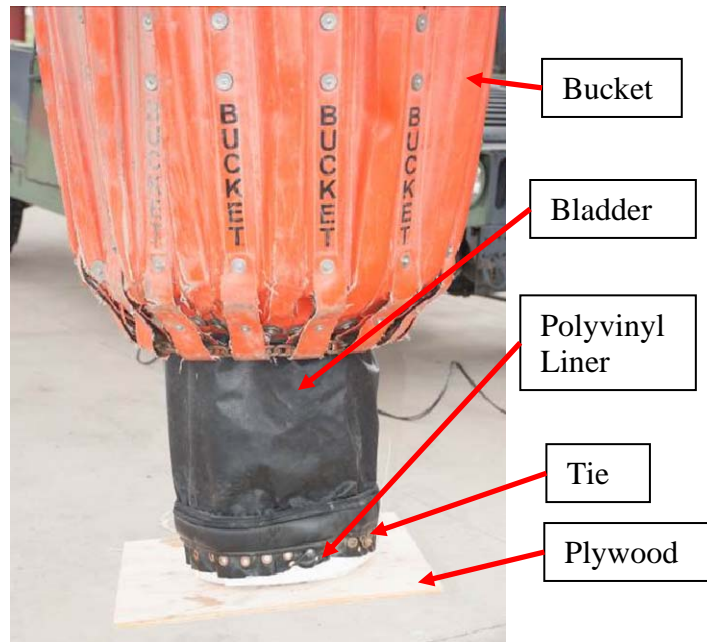


Figure 31: Configuration H03-006 (Exterior)

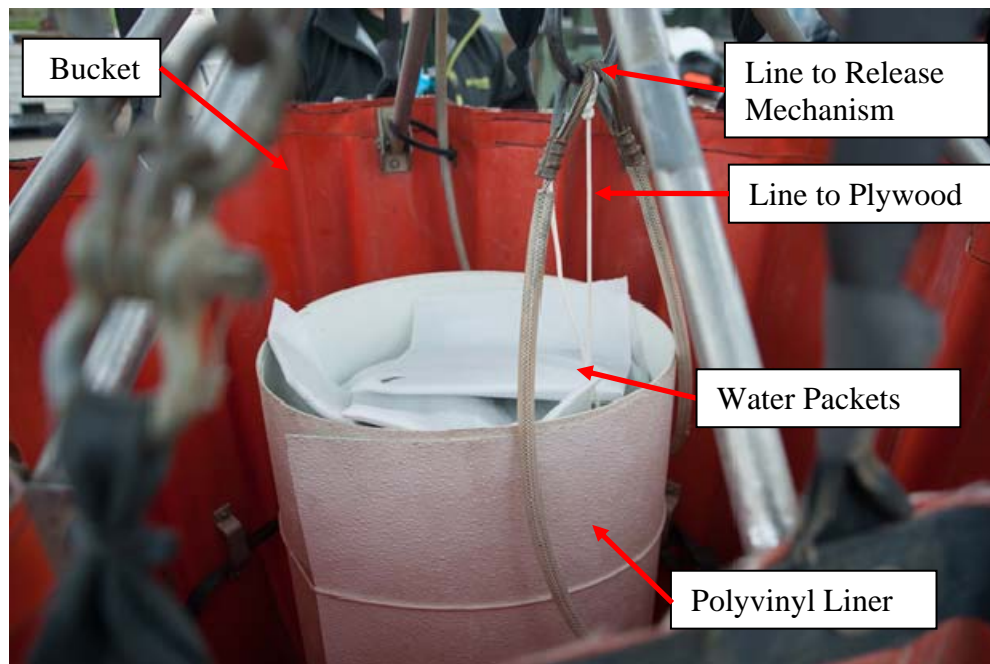


Figure 32: Configuration H03-006 (Interior)

The straight shape and smooth surface of the polyvinyl liner aided in the release of water packets. A conical shape was attempted for the liner; however, the friction between water packets created a bottleneck, preventing all items from evacuating the bucket. This configuration does not utilize the full size potential of the bucket but demonstrated it was possible to modify the current helicopter water bucket to deliver HOPE aid items.

3.2.3 HOPEFUL System Flight Test

The concepts were both tested under a helicopter to demonstrate the feasibility of deploying HOPE aid items from the cargo hook. The tests were conducted initially at low altitudes and airspeeds so the aircrew could gain experience and become accustomed to releasing the load with incremental increases to both altitude and airspeed to gain a better understanding of the payload flight dynamics.

3.2.3.1 Bucket Flight Demonstration

Flight testing of the water bucket was conducted at ATC under the UH-72 (Lakota) helicopter. The bucket was attached to the helicopter using standard procedures, and the water packets were placed into the bucket according to Section 3.2.2. The helicopter traveled to the designated DZ and activated the bucket, allowing the water packets to fall to the ground. The aircrew followed the test matrix identified in Table 8.

Table 8: Bucket Flight Demonstration Test Matrix

Drop #	Payload (lb)	Bucket Altitude (ft AGL)	Forward Airspeed (kts)	Results
20 November - Thursday				
H04-001	250	10	0	Items fell out of the bucket as designed. Small groupings of water packet contacted the ground
H04-002	250	20	20	Items fell out of the bucket as designed. Small groupings of water packet contacted the ground. Less than H04-001
H04-003	250	30	30	Items fell out of the bucket as designed. Small groupings of water packet contacted the ground. Less than H04-002
H04-004	250	40	40	Items fell out of the bucket prematurely. The plywood moved and forward airspeed kept plywood in the open position
H04-005	250	40	40	Added a ticket 3 tie prior to test. Items fell out of the bucket as designed.

The first flight was conducted with the aircraft hovering at low altitude. The helicopter lifted off and slowly proceeded to the DZ. The pilot activated the bucket and the water packets fell to the ground (Figure 33). The water packets left the bucket in a large grouping (about 35 water packets) and fell at a high speed. About 75% of the water packets survived the ground impact. It was assumed that with greater altitude and greater aircraft speed, the large grouping would break up, thereby providing greater survivability and safety.

The second and third flights were conducted at a greater air speed and altitude. Most water packets fell to the ground in a large grouping and at a high rate of speed while others fluttered to the ground. The grouping was about half as large as the hover tests, and there was a greater survivability



Figure 33: H04-001 Test

of the water packets on ground impact. Test H04-003 had about 5-10 water packets that escaped from the lower opening during flight. A double tie of ticket 3 (Figure 34) was added to the metal ring, which connects the release mechanism and the line attached to the plywood to prevent air from forcing aid items out of the mouth.

The fourth flight (H04-004) prematurely released the payload midflight. With increasing air speed, the bucket started to move to a position where it encroached upon the tail rotor. The increased drag force on the plywood caused the plywood to open and allowed the water packets to fall out of the bucket. In preparation for the next test, three single ties of ticket 3 were secured between the plywood and the mouth of the bucket to prevent the plywood from prematurely separating from the bucket mouth. Figure 35 shows the three ties, evenly spaced and attached to the mouth of the bucket.



Figure 34: H04-004 Ticket 3 Tie

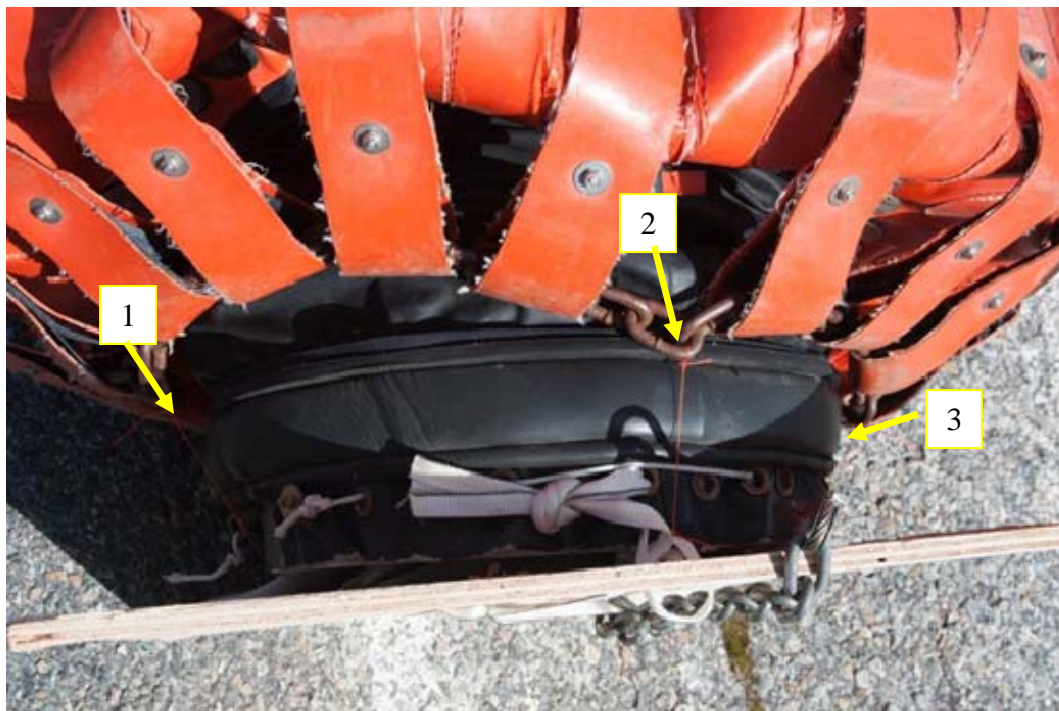


Figure 35: H04-005 Ticket 3 Tie

During test flight H04-005, the system functioned as designed. The aircraft lifted the payload to a height of 40-ft AGL, increased speed to 40-kts, and the pilot activated the bucket (Figure 36). No large groupings were observed, and the packets landed in an ellipse about 40 x 30-ft (Figure 37).



Figure 36: Flight H04-005 (release)



Figure 37: Flight H04-005 Packet Dispersion

3.2.4 Final HOPEFUL System Configuration

Flight testing of the HSL 10,000-lb cargo net rigged in the Concept 1 configuration was conducted at Redstone Test Center (RTC) under the UH-60 (Blackhawk) helicopter. Prior to testing, a series of aircraft maneuvers needed to be performed to understand the payload/aircraft limitations. Once the maneuvers were completed, the flight tests were conducted. About 1500 water packets were placed into the cargo net, which was then attached to the helicopter using the draft procedures dated 22 April 2015 (Appendix D). The helicopter traveled to the DZ and activated the net, allowing the water packets to fall to the ground. The aircrew followed the test matrix shown in Table 9.

Table 9: HSL Cargo Net Flight Test

Drop #	Payload (lb)	Bucket Altitude (ft AGL)	Forward Airspeed (kts)	Results
20 November - Thursday				
H05-001	1100	30	0	Good Release with minimal item dispersion. Items were in a circle about 20-ft in diameter
H05-002	1100	30	10	When the net was released, the net hung up but the system had a full deployment. The items had greater dispersion than from a hover. The items were in a circle about 25-ft in diameter with a small "tail" of decreasing density in the direction of flight.
H05-003	1100	30	20	Good Release with good item dispersion. The items were in a circle about 30-ft in diameter with a "tail" of decreasing density in the direction of flight.

The test pilots were concerned that the residuals would not be heavy enough to keep the net below the aircraft, creating a potentially dangerous situation as well as a concern that the full system might accidentally activate at a speed greater than the empty net speed, putting the aircrew into a dangerous situation. RTC determined that it would be best to conduct the low speed maneuvers with a full net, activate the net, and then conduct all maneuvers with the empty net. This order would properly organize the net and residual equipment into the post-release configuration with the cargo net balled up at the end of the retention line.

The net was prepared per the draft rigging manual and attached to the helicopter. The aircraft completed the low speed flight maneuver list consisting of turns and slides with increasing speed both in and out of ground effect. The aircraft then proceeded to the DZ, and the crew chief activated the net. The water packets fell to the ground, leaving the residual equipment attached to the aircraft. The helicopter then conducted the same low speed maneuvers with the empty net with the cargo net balled up at the end of the retention line. Once the low speed maneuvers were completed with the empty net, the pilots evaluated the high speed flight characteristics of the empty net system. These maneuvers consisted of forward flight with ascending and descending turns. The last maneuver was to identify the maximum flight speed of the empty net. The empty net critical speed was identified as 75-kts and therefore the safe flight speed was identified at 60-kts with a 15-kts safety factor.

The second load was prepared and rigged per the draft rigging manual then attached to the helicopter. The pilot completed the remainder of the forward flight maneuvers with the full cargo net and proceeded to the DZ to release the payload. As the aircraft passed the observation point, an entanglement in the suspension legs of the net was observed (Figure 38). When the crew chief activated the net for the second time, most of the water packets fell from the net, but some remained in the net. Upon inspection, one of the suspension legs was secured through another suspension leg creating a tension knot (Figure 39). This knot was the result of a rigging error and did not allow all items to fall away as designed.



Figure 38: HSL Cargo Net Entanglement



Figure 39: Tension Knot

The third payload was rigged in the same manner as the others, with additional attention to detail to ensure the suspension slings did not entangle. The net was attached to the cargo hook, the aircraft proceeded to the DZ, and the net was activated per the conditions in Table 9. The net fell away and the packets descended to the ground in a large group. Figure 40 shows the system after activation with a large grouping of water packets falling towards the ground. Figure 41

shows the dispersion of the aid items in a grouping of about 30-ft in diameter and the tail with decreasing item density. It is assumed that with the increase of altitude, the dispersion footprint would increase and the aid item density would decrease. This change in altitude would allow for a greater coverage area.



Figure 40: HSL Cargo Net Deployment



Figure 41: HSL Cargo Net Aid Item Dispersion

3.2.5 HOPEFUL Testing Observations

Testing has demonstrated it is possible to sling aid items beneath a helicopter and disperse them at a desired location. The water bucket concept demonstrated the feasibility of delivering aid items, but there were many issues that made this system less effective and user friendly. The bucket system needed to have a low friction liner inserted into the bucket, which limited the amount of aid items being delivered. There was also a need to modify the opening method of the bucket to allow the aid items to fall to the ground. Although the system easily integrates into the aircraft, the modifications to the system increase complexity and decrease the amount of aid that can be delivered in a single sortie.

The HSL cargo net system also demonstrated the feasibility of delivering aid items from a helicopter underslung load. This system used fielded equipment with slight reconfiguration of the cargo net. The system also used standard Air Force equipment to activate the release. Because the WGRM and MSC were not designed for rotary wing aircraft, there are a few user-interface issues. These issues could be overcome with a modification to add a button that would allow the MSC to easily transition from fixed wing aircraft to rotary wing aircraft use. The other hardware components would need to be evaluated to accommodate more water packets and ensure easier rigging. The cargo net system has shown that delivering humanitarian aid from the cargo hook of a helicopter is a viable solution.

4 Humanitarian Airdrop Modeling

Two mathematical models were developed for further analytical assessment of humanitarian airdrop concepts. The first model utilized airdrop parameters associated with an airdrop mission to predict aid item dispersion and density as well as the landing location of the residual equipment. This model can also be used to calculate some airdrop parameters given a desired dispersion footprint and density. The second model supported strategic logistics planning and cost assessment of humanitarian airdrops. The logistics planning shows times to complete the mission, from the request to the point of delivery, as well as the costs associated with the delivery process.

4.1 Aid Item Dispersion Modeling

Aid item dispersion modeling was conducted by the Charles Stark Draper Laboratory under contract with NSRDEC and funded by the AFRL and NSRDEC. Data on each of the airdrops were collected and provided to Draper Labs, which analyzed the data and updated software to predict the aid item dispersion footprint on the ground given various airdrop parameters. The intent was to predict the aid item dispersion footprint and density given the payload transition conditions or calculate the payload transition conditions needed given a desired aid item dispersion footprint and density.

Aid item dispersion is affected by many factors, such as the deployment altitude, transition altitude, and wind profile during air item descent. The transition altitude has the greatest effect on the dispersion footprint since at this stage in the system, the aid item “cloud” is created. The greater the altitude, the longer the “cloud” is exposed to the prevailing winds. The aid item dispersion footprint data have been collected on every drop along with the corresponding wind patterns. These data are currently being consolidated into a dispersion model outlined in a previous American Institute of Aeronautics and Astronautics conference paper titled “*Delivery of Humanitarian Aid onto Active Populations*” [13]. Transition occurred at altitudes between 500 and 3000-ft AGL with the majority of transition altitudes at approximately 1000-ft AGL. The midair dispersion is modeled as an ellipsoid formed about a centroid with an origin at the transition event (Figure 42). The ellipsoid expands based on the minimum and maximum descent rates of the aid items with some influence from any constant winds. The ellipsoid essentially “lays down” on ground impact, generating a two dimensional aid item dispersion footprint at which point gusting winds dictate small changes in dispersion shape. This dispersion data, weather balloon data, and trajectory information gathered by onboard instrumentation will be used to form the aerodynamic variables used in the dispersion modeling software and ultimately validate the software package.

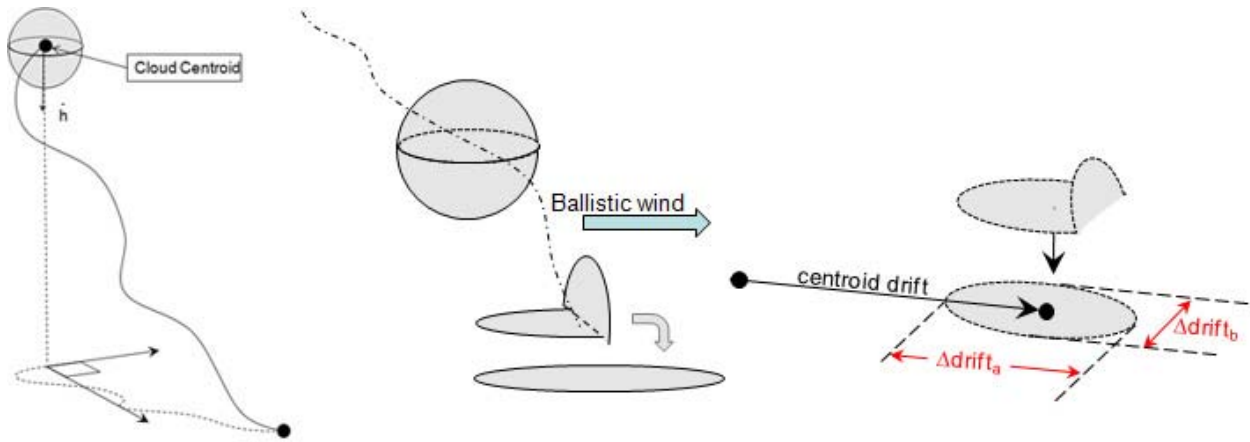


Figure 42: Modeling the dispersion cloud as an ellipsoid to generate a footprint

Figure 43 shows two aid item dispersion footprints, where the solid arrows are constant winds and the dotted arrow is the gusting winds recorded on the DZ at the time of the airdrop. In both instances the direction of flight was North to South. Each is a single payload with the same approximate transition altitude (1000-ft AGL) separated by 20 h. The plot on the left (017-005) had constant winds of about 12.8-kts without wind gusts, while the plot on the right (017-11) had a constant wind of about 12.0-kts with a gust of about 16.0-kts near the ground. This gust is believed to create the concaved section located in the lower section of the right plot (017-011).

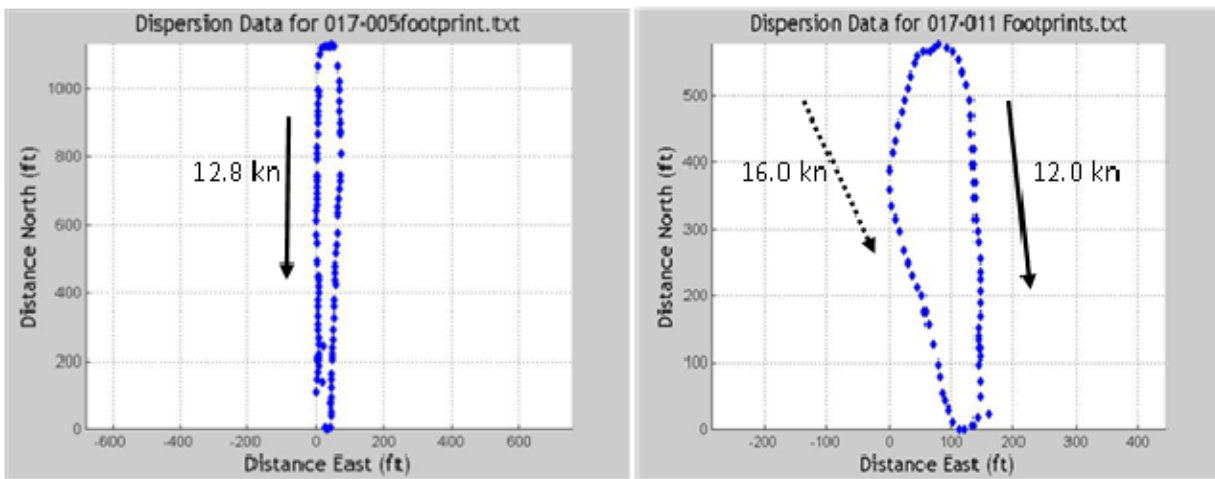


Figure 43: Comparison of constant winds verses gusting winds on aid item dispersion footprint

Figure 44 shows the two aid item dispersion footprints. Each is a single payload with the same approximate transition altitude during the same test day. The plot on the left (drop 338) did not have any measureable wind. The plot on the right (drop 337) also did not have any measureable constant wind, but there was a gust of about 2.9-kts. Again, it is believed this gust created the concaved section located in the lower section of the right plot (drop 337). The dispersion footprint is relatively similar in both cases and the distribution of aid items is also consistent. Figure 45 shows the typical dispersion of aid items from the ground point of view.

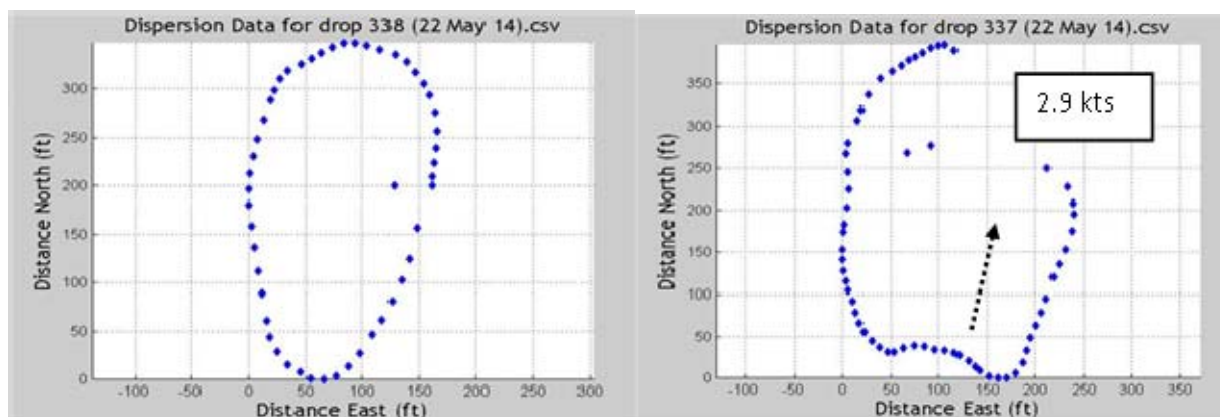


Figure 44: Comparison of no winds condition verses gusting winds on aid item dispersion footprint



Figure 45: Typical dispersion of a single bundle

4.2 Humanitarian Logistic Modeling

The Army Research Laboratory and the National Science Foundation funded the research and development of a statistical model and planning tool to support humanitarian aid missions. The intent of the study was to identify the trade-offs between various supply chain components (cost and time) and their responsiveness to an event. NSRDEC supported the project by providing information on the humanitarian aid distribution network and observed the research to inform the HOPE program.

The report generated by Nathaniel Bastian [14] identified current U.S. Air Force locations with cargo aircraft capable of responding to a disaster, proximity to high disaster risk areas, and storage space available to support a humanitarian operation. The project then generated a humanitarian airdrop process flow chart documenting the entire process. The project used these data to generate a stochastic, mixed integer, weighted goal programming model for strategic logistics planning and a cost assessment capability to analyze the potential cost savings to the entire humanitarian supply network.

The current humanitarian network provided an average response within 6 days and a supply chain cost of \$153 billion. The model showed there were direct correlations between mission costs and unmet demand. It was also shown that as the flight time budget was increased, the average response time and supply chain cost increased and the unmet demand decreased. All factors could be adjusted based on the needs of decision makers to decrease time of delivery, cost, or any other factor.

5 Conclusions and Recommendations

The capability of delivering and dispersing humanitarian aid items safely over a populated area discussed in this paper addresses the concerns associated with current humanitarian aerial delivery methods. Like TRIADS, ground forces are not needed to secure the DZ, thereby preventing the need to put personnel in harm's way. The dispersion technique, in conjunction with the foam on the underside of the skidboard, reduced concerns of injury to the underlying population. The aid items flutter downward and impact the ground with less than 3100N, which will not cause serious harm to a person should they be in the flight path. The dispersion pattern also reduces the chances that the strong or weapon-wielding population will take control of the container and ration out the aid as they see fit. This system does not significantly increase the burden on the aircraft crew, other than programming the iWAD, because all the components leave the aircraft with the payload and it utilizes standard CDS airdrop procedures.

There are more cost-effective methods for delivering large quantities of aid items to a population; however, those methods require intact and functioning infrastructure in the disaster area such as airfields, ports, and roads. This system was developed for a quick response within the first few days after an incident with the intent of using more cost-effective methods for follow-on support. A fully rigged payload contains at least 900-lb (2,400 4-oz water packages per bundle). A C-17 can carry a total of 40 CDS bundles equating to nearly 6,000-gal of water. With a conservative 25% loss rate (unfound and damaged packages), and an estimate of 80-oz of water required by each person per day (150-lb average human weight in warm weather) this would result in one fully loaded C-17 hydrating a minimum of 7,200 people for a day.

The HOPE airdrop system design has proved to be a reliable method of delivering and dispersing small items while avoiding clumping and transition failure issues that were prevalent in the initial stages of this effort. The aid items developed during this program with the foam overlay have been shown through analysis to cause less injury when compared to current aid items delivered via airdrop. With 113 test samples, the concept has demonstrated a 94.7% success rate, with six payload failures.

One issue identified in airdrop testing still remains: the retention of the boxes to the activation line. As the aid items are expelled from their boxes, they impact the lower layers of boxes with high force, causing some boxes to detach from the activation line. Figure 46 shows the initial moments of the transition phase. While the contents of the detached boxes are still dispersed, it presents an additional failure risk.

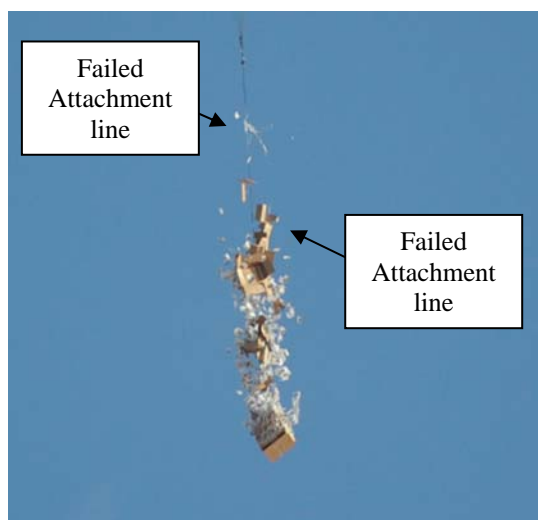


Figure 46: Impact of aid items from higher layers onto below layers, causing box damage

The impact force of the falling sections of damaged boxes was calculated to be about 1000N, which is less than the previously identified critical shear force of 3100N. These calculations are based off the largest sections of cardboard found on the drop zone after an airdrop and a review of the drop test video where these items were tracked from transition to ground contact. These sections of packaging were found to fall slower than the aid item “cloud” and the parachute with all of the residual items attached (Figure 47).

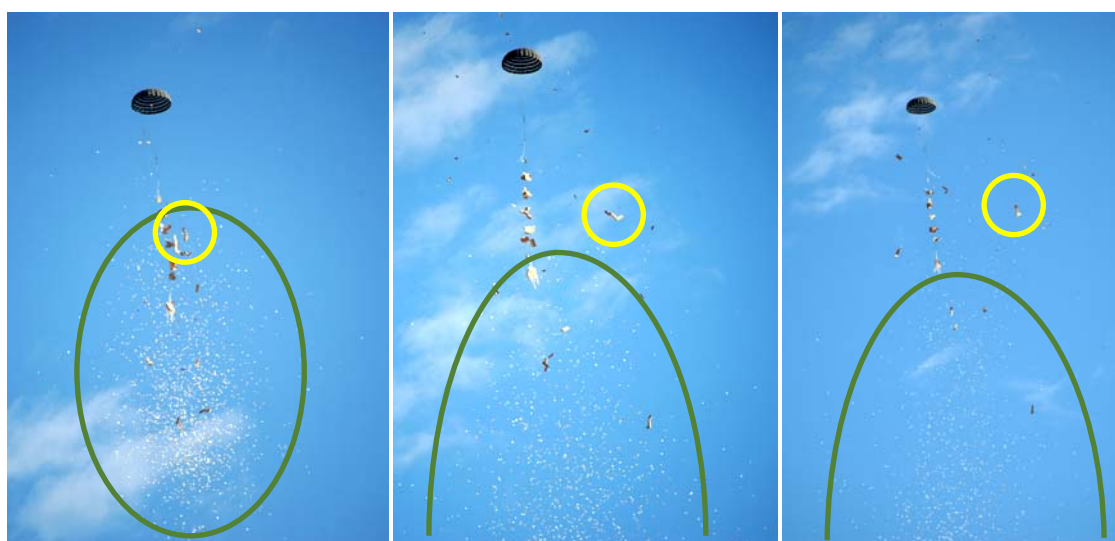


Figure 47: Tracking of a typical damaged segment of a cardboard box with respect to the dispersion cloud

The HOPE system does have some unaddressed issues, such as the need to reduce the size of the aforementioned cardboard box sections or retaining the boxes to the deployment line; however, the prototype system demonstrated all program “desirements” and the refinement of the system should be continued.

This document reports research undertaken at the U.S. Army Natick Soldier Research, Development and Engineering Center, Natick, MA, and has been assigned No. NATICK/TR- 17/018 in a series of reports approved for publication.

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Appendix A

HOPE Test Dates and Configuration

Date	# of Payloads	TRW (lb)	Item Type	Planned HALO Time (s)	Drop Altitude (ft MSL)	Aircraft	Planned Dispersion Alt (ft MSL)
6-Nov-12	1	625	Natick Water Packets (12"x12" area)	50.2	6549	SkyVan	3049
6-Nov-12	1	700	Natick Water Packets (12"x12" area)	47.6	6549	SkyVan	3049
7-Nov-12	1	675	Natick Water Packets (12"x12" area)	49.3	6549	SkyVan	3049
10-Dec-12	1	820	Natick Water Packets (12"x12" area)	44.6	6300	C-130J	2800
10-Dec-12	1	1276	Wood Blocks	36.5	6300	C-130J	2800
10-Dec-12	1	1266	Wood Blocks	36.6	6300	C-130J	2800
10-Dec-12	1	1250	Wood Blocks	36.8	6300	C-130J	2800
11-Dec-12	1	735	Rubber Blocks	92.4	9999	C-130J	2800
11-Dec-12	1	746	Rubber Blocks	91.8	9999	C-130J	2800
12-Dec-12	1	797	Natick Water Packets (12"x12" area)	144.1	15000	C-130J	2800
12-Dec-12	1	1054	Wood Blocks	125.8	15000	C-130J	2800
29-Jan-13	1	872	Top 2 layers 9x9" water packets, bottom 4 wood blocks	168.9	17500	C-17	2300
29-Jan-13	1	854	Top 2 layers 9x9" water packets, bottom 4 wood blocks	170.6	17500	C-17	2300
29-Jan-13	1	843	Top 2 layers 9x9" water packets, bottom 4 wood blocks	171.7	15000	C-17	2300
29-Jan-13	1	840	Top 2 layers 9x9" water packets, bottom 4 wood blocks	172.0	15000	C-17	2300
30-Jan-13	1	860	Top 2 layers 9x9" water packets, bottom 4 wood blocks	67.4	9999	C-130H	4300

30-Jan-13	1	840	Top 2 layers 9x9" water packets, bottom 4 wood blocks	73.5	9999	C-130H	3800
30-Jan-13	1	839	Top 2 layers 9x9" water packets, bottom 4 wood blocks	79.6	9999	C-130H	3300
31-Jan-13	1	966	All Wood	214.1	24999	C-130H	1800
31-Jan-13	1	857	Top 2 layers 12x12" water packets, bottom 4 wood blocks	227.1	24999	C-130H	3300
31-Jan-13	1	820	Top 2 layers 9x9" water packets, bottom 4 wood blocks	232.0	24999	C-130H	3300
31-Jan-13	1	804	Top 2 layers 9x9" water packets, bottom 4 wood blocks	234.3	24999	C-130H	3300
25-Feb-13	1	850	Top 2 layers 9x9" water packets, bottom 4 wood blocks	92.4	9999	C-130H	2300
25-Feb-13	1	856	Top 2 layers 9x9" water packets, bottom 4 wood blocks	85.9	9999	C-130H	2800
25-Feb-13	1	862	Top 2 layers 9x9" water packets, bottom 4 wood blocks	79.5	9999	C-130H	3300
25-Feb-13	1	881	Top 2 layers 9x9" water packets, bottom 4 wood blocks	72.6	9999	C-130H	3800
26-Feb-13	1	868	Top layer water packets, bottom 5 layers wood blocks	149.6	9999	MC-130	2300
26-Feb-13	1	891	Top layer water packets, bottom 5 layers wood blocks	137.6	9999	MC-130	2800
26-Feb-13	1	892	Top layer water packets, bottom 5 layers wood blocks	127.5	9999	MC-130	3300
26-Feb-13	1	904	Top layer water packets, bottom 5 layers wood blocks	116.9	9999	MC-130	3800
27-Feb-13	1	887	Top layer water packets, bottom 5 layers wood blocks	146.4	9999	MC-130	2300
27-Feb-13	1	882	Top layer water packets, bottom 5 layers wood blocks	136.8	9999	MC-130	2800

2-Apr-13	1	808	Top layer water packets, bottom 5 layers wood blocks	131.1	9999	C-130J	3185
2-Apr-13	1	838	Top layer water packets, bottom 5 layers wood blocks	136.4	9999	C-130J	2800
2-Apr-13	1	847	Top layer water packets, bottom 5 layers wood blocks	145.6	9999	C-130J	2300
2-Apr-13	1	874	Top layer water packets, bottom 5 layers wood blocks	153.1	9999	C-130J	1800
3-Apr-13	1	796	Top 2 layers water, bottom 4 layers wood blocks	135.8	9999	C-130J	2998
3-Apr-13	1	833	Top 2 layers water, bottom 4 layers wood blocks	136.8	9999	C-130J	2800
3-Apr-13	1	845	Top 2 layers water, bottom 4 layers wood blocks	145.7	9999	C-130J	2300
3-Apr-13	1	845	Top 2 layers water, bottom 4 layers wood blocks	155.7	9999	C-130J	1800
6-May-13	1	854	Top 2 layers water, bottom 4 layers wood blocks	131.2	9999	C-130J	3000
6-May-13	1	862	Top 2 layers water, bottom 4 layers wood blocks	134.5	9999	C-130J	2800
6-May-13	1	866	Top 2 layers water, bottom 4 layers wood blocks	144.0	9999	C-130J	2300
6-May-13	1	867	Top 2 layers water, bottom 4 layers wood blocks	153.8	9999	C-130J	1800
7-May-13	1	875	Top 2 layers water, bottom 4 layers wood blocks	129.6	9999	C-130H	3000
7-May-13	1	901	Top 2 layers water, bottom 4 layers wood blocks	131.6	9999	C-130H	2800
7-May-13	1	906	Top 2 layers water, bottom 4 layers wood blocks	140.8	9999	C-130H	2300

7-May-13	1	910	Top 2 layers water, bottom 4 layers wood blocks	150.1	9999	C-130H	1800
8-May-13	2	912	Top 2 layers water, bottom 4 layers wood blocks	127.0	9999	C-130H	3000
8-May-13	1	903	Top 2 layers water, bottom 4 layers wood blocks	146.8	9999	C-130H	2000
9-May-13	1	950	Top 3 layers water, bottom 3 layers wood blocks	128.2	9999	C-130H	2800
9-May-13	1	962	Top 3 layers water, bottom 3 layers wood blocks	136.7	9999	C-130H	2300
29-Oct-13	1	933	6 Layers PARC packed water	47.9	6300	C-130H	2300
29-Oct-13	1	929	6 Layers PARC packed water	48.0	6300	C-130H	2300
31-Oct-13	1	950	6 Layers PARC packed water	73.9	6300	C-130H	2300
31-Oct-13	1	950	6 Layers PARC packed water	73.9	6300	C-130H	2300
31-Oct-13	1	934	6 Layers PARC packed water	74.5	6300	C-130H	2300
19-Nov-13	1	948	6 Layers PARC packed water	55.3	6300	C-130H	3300
19-Nov-13	1	950	6 Layers PARC packed water	64.6	6300	C-130H	2800
19-Nov-13	1	945	6 Layers PARC packed water	74.1	6300	C-130H	2300
19-Nov-13	1	942	6 Layers PARC packed water	83.7	6300	C-130H	1800
20-Nov-13	1	947	6 Layers PARC packed water	55.4	6300	C-130H	3300
20-Nov-13	1	953	6 Layers PARC packed water	64.5	6300	C-130H	2800
20-Nov-13	1	934	6 Layers PARC packed water	74.5	6300	C-130H	2300
20-Nov-13	1	940	6 Layers PARC packed water	83.8	6300	C-130H	1800
10-Mar-14	1	934	6 Layers PARC packed water	47.3	6300	C-130H	3800

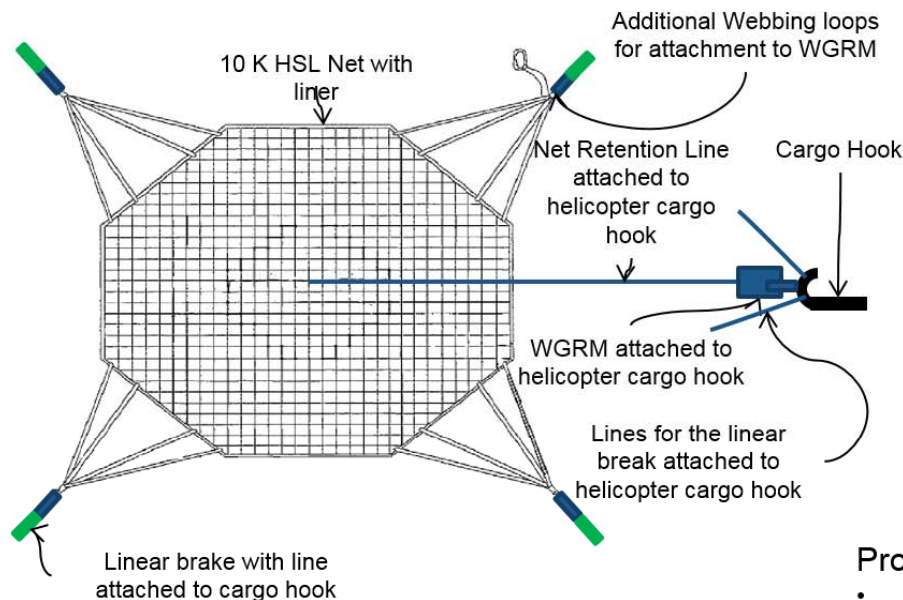
10-Mar-14	1	964	6 Layers PARC packed water	47.3	6300	C-130H	3800
10-Mar-14	1	943	6 Layers PARC packed water	47.3	6300	C-130H	3800
11-Mar-14	1	960	6 Layers PARC packed water	51.3	6300	C-130H	3500
11-Mar-14	1	958	6 Layers PARC packed water	51.3	6300	C-130H	3500
11-Mar-14	1	933	6 Layers PARC packed water	51.3	6300	C-130H	3500
11-Mar-14	1	939	6 Layers PARC packed water	51.3	6300	C-130H	3500
12-Mar-14	1	934	6 Layers PARC packed water	55.8	5300	C-130H	2300
12-Mar-14	1	938	6 Layers PARC packed water	55.8	5300	C-130H	2300
12-Mar-14	1	929	6 Layers PARC packed water	55.8	5300	C-130H	2300
12-Mar-14	1	930	6 Layers PARC packed water	55.8	5300	C-130H	2300
12-Mar-14	1	933	6 Layers PARC packed water	55.8	5300	C-130H	2300
21-May-14	1	931	1-layer PARC packed water 5-layer wood ballast	55.8	5300	C-130H	2300
21-May-14	1	929	6-layers PARC packed water Top layer painted orange, bottom green	55.8	5300	C-130H	2300
21-May-14	3	940	6 Layers PARC packed water	55.8	5300	C-130H	2300
21-May-14	1	946	6-layers PARC packed water Top layer painted orange, bottom green	55.8	5300	C-130H	2300
22-May-14	3	945	6 Layers PARC packed water	55.8	5300	C-130H	2300
22-May-14	1	939	6 Layers PARC packed water	55.8	5300	C-130H	2300
22-May-14	1	939	6 Layers PARC packed water	55.8	5300	C-130H	2300
22-Jul-14	2	950	6 Layers PARC packed water	55.8	5300	C-130H	2800

22-Jul-14	2	964	6 Layers PARC packed water	55.8	5300	C-130H	2800
23-Jul-14	2	954	6 Layers PARC packed water	55.8	5300	C-130H	3800
23-Jul-14	2	950	6 Layers PARC packed water	55.8	5300	C-130H	2800
24-Mar-15	5	936	6-layers YPG packed water with stiffeners	55.8	5300	C-130H	2800
26-Mar-15	10	971	6-layers YPG packed water with stiffeners	55.8	5300	C-130H	2800

Appendix B

HOPEFUL Generated Concepts

Concept 1: Single Net



Method of Activation

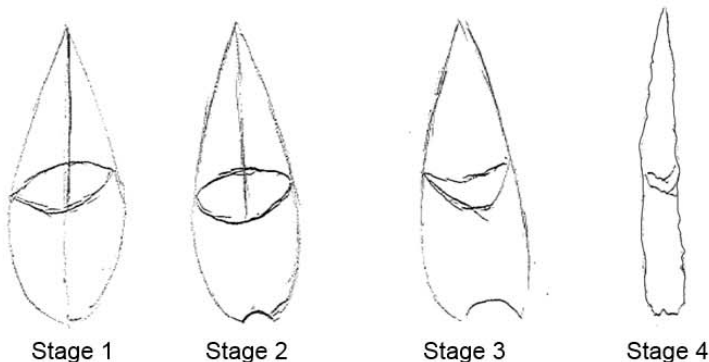
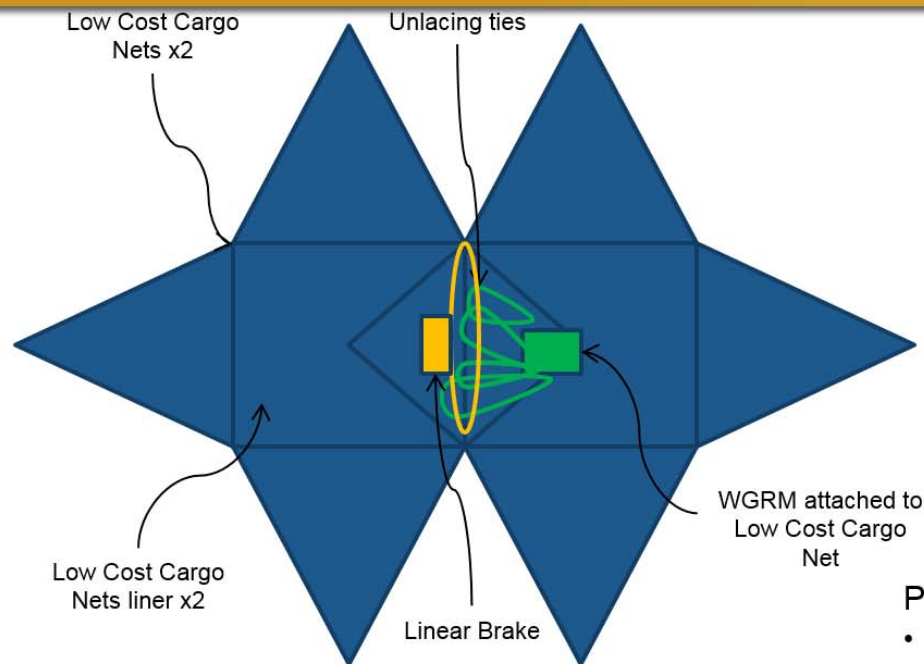
- **STAGE 1:** The lines for the linear brakes are secured to the linear brake and the additional webbing loops are attached to the WGRM.
- **STAGE 2:** The WGRM releases the additional webbing loops, allowing the weight of the payload to pull on the linear brake. The aid items will start to spill over the edge of the net.
- **STAGE 3:** The line attached to the linear brake continues to play out and allowing more aid items to spill over the edge.
- **STAGE 4:** The line ends, allowing the four linear breaks to fall dumping the remaining aid items.

Pro

- The system utilizes currently fielded equipment with minimal fabrication/modification
- Easy to rig the payload
- All residual items can be recovered and reused
- Work with current food bars but modification would be required for water

Con

- There is potential for significant clumping of aid items, increasing decent rate of packages
- Some fabrication/modification is required
- Items would be required to be emptied out of storage boxes and placed into large net
- The pressure of all aid items on top of the bottom level of aid items may causing bursting and damage.
- Previous testing has shown high clumping potential



Method of Activation

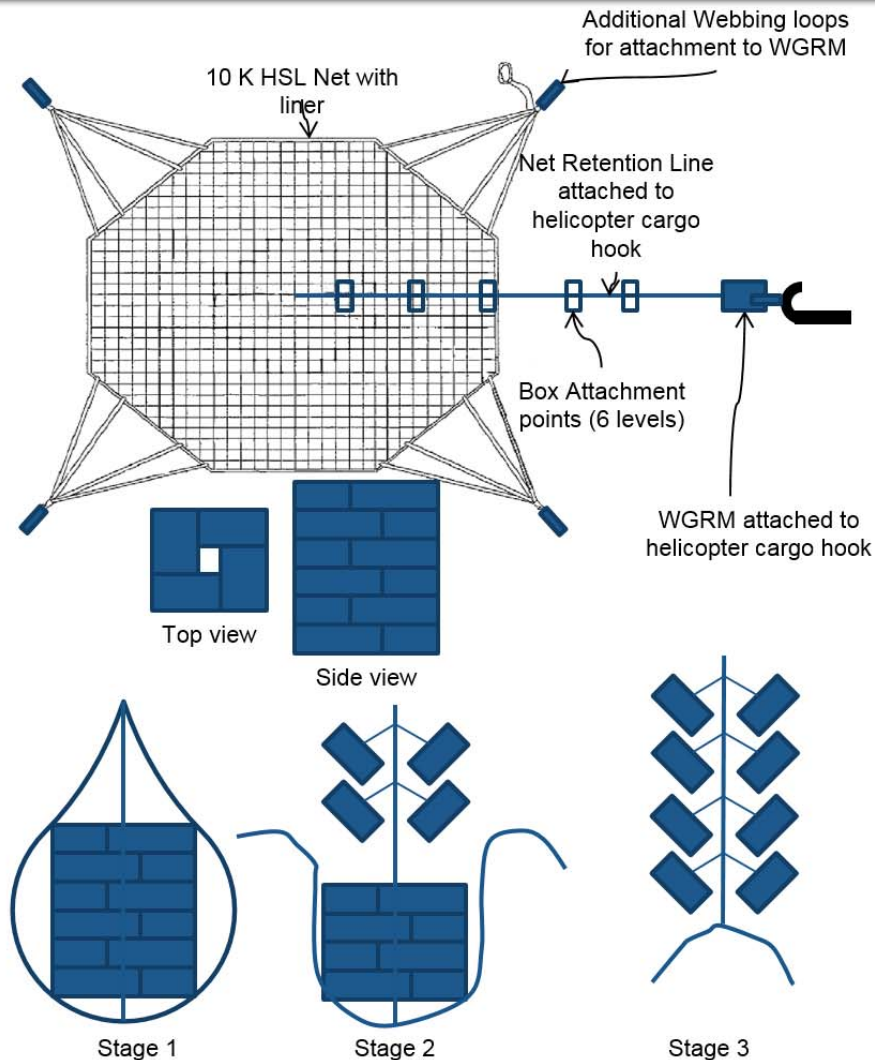
- **STAGE 1:** The 6 legs of the low cost cargo nets are attached to the cargo hook of the helicopter, with the aid items within. The remaining 2 legs are folded over themselves, leaving an opening between the two net. There is a WGRM attached to one cargo net and multiple unlacing ties, securing the two ends of the net together.
- **STAGE 2:** The WGRM releases the unlacing ties, allowing the aid items to fall through the hole between the nets.
- **STAGE 3:** The linear brake slowly releases the line, allowing the hole between the nets to get bigger.
- **STAGE 4:** All of the aid items have escaped through the hole between the nets.

Pro

- Easy to rig the payload
- Can deliver more aid items than a single cargo net
- All residual items can be recovered and reused

Con

- There is potential for significant clumping of aid items, increasing decent rate of packages
- Some fabrication/modification is required
- Items would be required to be emptied out of storage boxes and placed into large net
- The pressure of all aid items on top of the bottom level of aid items may causing bursting and damage.
- Long loiter times due to slowly releases aid items



Method of Activation

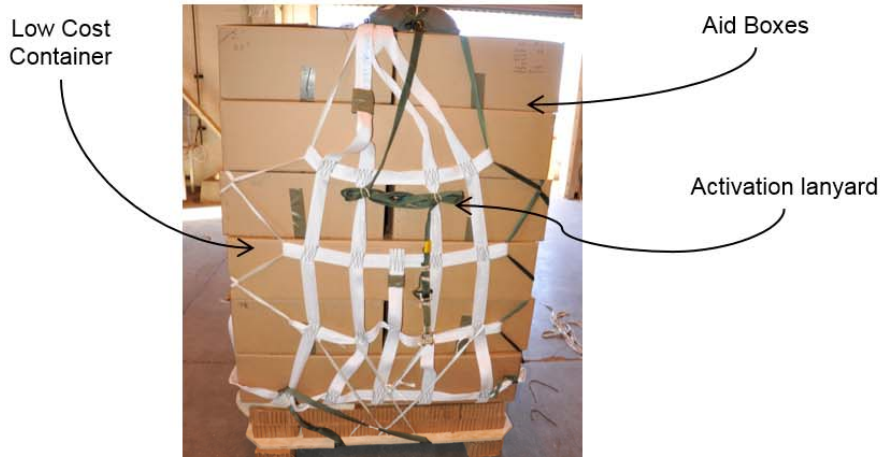
- **STAGE 1:** The HOPE boxes are stacked in the HSL net with the lanyards attached to the activation line. The ends of the HSL net are attached to the WGRM. The WGRM and the activation line are attached to the helicopter cargo hook.
- **STAGE 2:** The WGRM releases the ends of the Helicopter cargo net, allowing the payload to drop away from the helicopter. The boxes are pulled off of the top of the falling payload. The boxes flip and dump the content of the box.
- **STAGE 3:** The boxes are empty and retained to the activation line.

Pro

- The system utilizes currently fielded equipment with minimal fabrication/modification
- Utilized most of the HOPE airdrop equipment
- The system uses the current boxes that the packages are stored and shipped in.
- Easy to rig the payload

Con

- Some fabrication/modification is required
- The boxes would be required for the next humanitarian mission.



Utilize the current HOPE airdrop rigging payload and remove the items that are not needed. These items would be the parachute, iWAD, Foam and honeycomb. There is potential to remove the skidboard as well.



Stage 1

Stage 1

Stage 1

Stage 1

Method of Activation

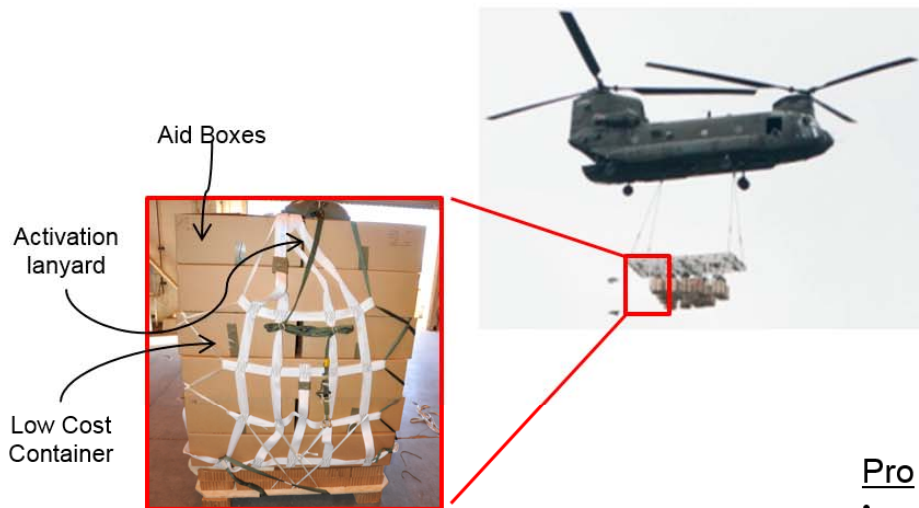
- **STAGE 1:** The HOPE boxes are stack in the low cost container with the lanyards attached to the activation line. The ends of the low cost container are attached to the WGRM. The WGRM and the activation line are attached to the helicopter cargo hook.
- **STAGE 2:** The WGRM releases the ends of the low cost container, allowing the payload to drop away from the helicopter. The boxes are pulled off of the top of the falling payload. The boxes flip and dump the content of the box.
- **STAGE 3:** The boxes are empty and retained to the activation line.

Pro

- The system utilizes current HOPE rigging procedures with minimal modification
- Utilized most of the HOPE airdrop equipment
- The system uses the current boxes that the packages are stored and shipped in.
- Easy to rig the payload
- System has been demonstrated in an airdrop application
- Potential to have 4 payloads on 1 hook or 1-4 on each hook of a CH-47 Chinook

Con

- Some fabrication/modification is required
- The boxes would be required for the next humanitarian mission.
- Limited amount of aid items



Method of Activation

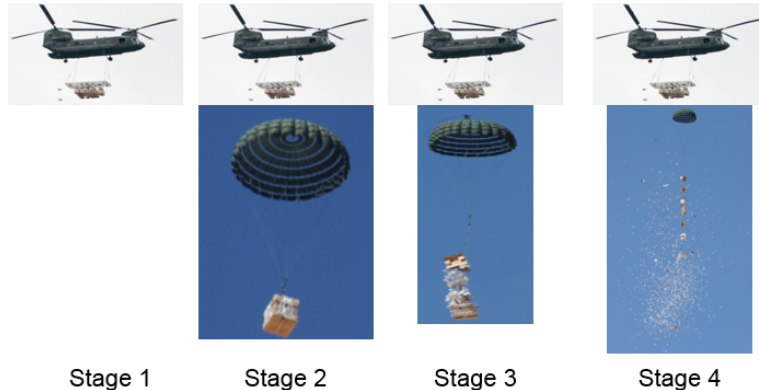
- STAGE 1: The HOPE airdrop payloads are attached to the HSL RADE and the Aircraft flies to the designated location.
- STAGE 2: The Crew Chief activated the WGRM activating the deployment of the payload. The payload descends until activation altitude.
- STAGE 3: The payload reaches activation altitude and deploys the aid items on are dispersed from the payload
- STAGE 4: The residuals descend to the ground along with the aid items

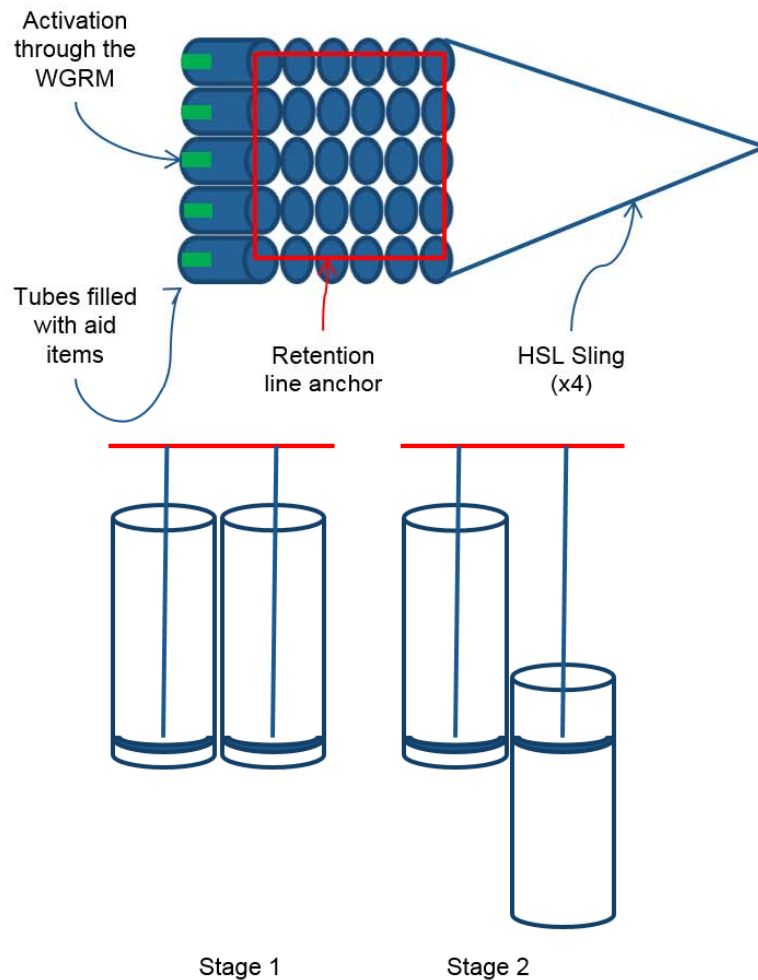
Pro

- The system utilizes current HOPE rigging procedures with minimal modification
- Utilized the HOPE airdrop equipment
- The system uses the current boxes that the packages are stored and shipped in.
- Easy to rig the payload
- System has been demonstrated in an airdrop application
- Potential to have 16 payloads on 2 hooks under the helicopter
- AWR already issued

Con

- Some fabrication/modification is required
- The boxes would be required for the next humanitarian mission.
- Damage from adjacent loads during flight
- Payload center of balance issues and hook loading limitations of the CH-53
- Issues with the boxes losing strength when in contact with water





Method of Activation

- STAGE 1: The HOPE airdrop items are placed into tubes with a plunger on the bottom. The aircraft flies to the designated DZ/LZ.
- STAGE 2: The Crew Chief activated the WGRM activating the deployment of the payload. The tube descends until the packets are released through the top of the tube.

Pro

- Easy to rig the payload
- Can deploy items at multiple locations or stage the deployment at one location
- All residual items can be recovered and reused
- Work with current aid items

Con

- Full system requires development with fabrication and testing.
- Items would be required to be emptied out of storage boxes and placed into large net
- Discard the boxes which the items were previously stored.
- Multiple WGRM's required for each action (payload staging, multiple DZ/LZ, ect.)

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Appendix C

Helicopter Water Bucket Ground Test Configurations



Figure C-1: Water Bucket Configuration 003-001

Configuration 003-001 used the bucket as designed with minimal modifications. The lacing on the bladder was rerouted so the lines would not interfere with the water packets exiting the bucket through the center opening.



Figure C-2: Water Bucket Configuration 003-002

Configuration 003-002 used the same configuration as 003-001 with the exception of a single clevis tied to the lip of the center opening. The thought was the water packets were not providing enough force on the bladder to cause the bladder to invert and open.



Figure C-3: Water Bucket Configuration 003-003



Figure C-4: Water Bucket Configuration 003-004

Configurations 003-003 and 003-004 used the same configuration as 003-002 with the exception of two and three clevis, respectively, tied to the lip of the center opening.

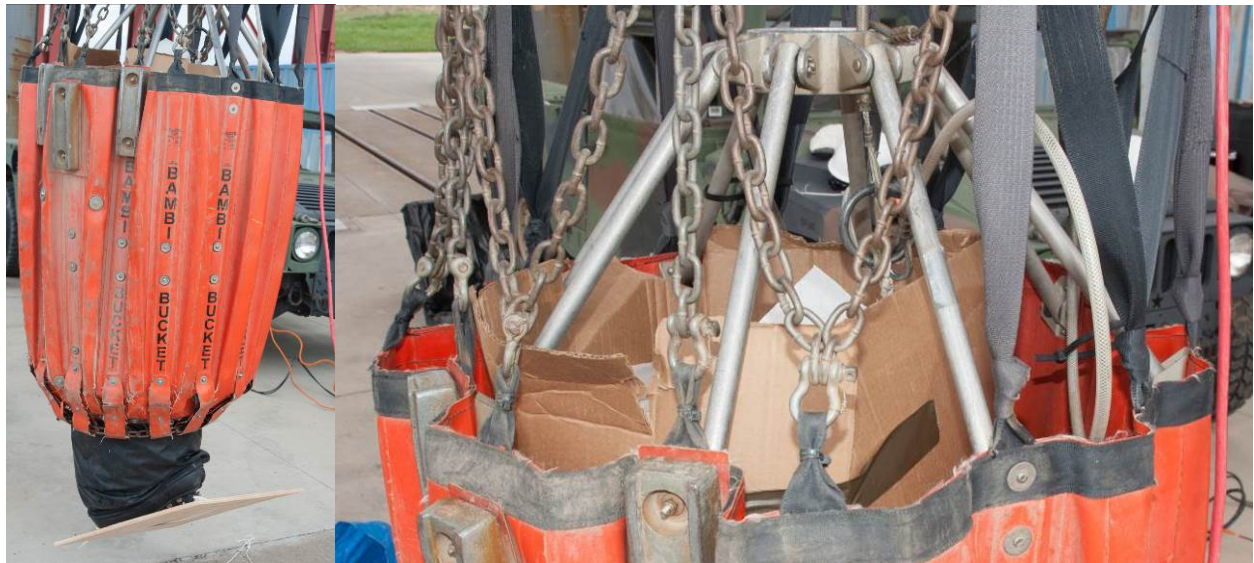


Figure C-5: Water Bucket Configuration 003-005

Configuration 003-005 used a different configuration than any tested to this point. The bladder was extended with a plywood board serving as a release gate. The activation line that extends to the lacing was detached from the bladder and attached to a plywood board. A cardboard liner was placed in the bucket to act as a funnel. It was assumed the cardboard would have a lower coefficient of friction and would allow the packets to fall out of the bucket.



Figure C-6: Water Bucket Configuration 003-006

Configuration 003-006 used the same configuration as 003-005 with the exception of the cardboard liner. A polyvinyl tube was used because it had a lower coefficient of friction than the cardboard and it had a straight shape. The funnel design used in 003-005 caused a bottleneck and would not allow the packets to fall out of the bucket.

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Appendix D **Humanitarian Operations Packaged Essentials (HOPE) from a Helicopter Draft** **Rigging Manual**

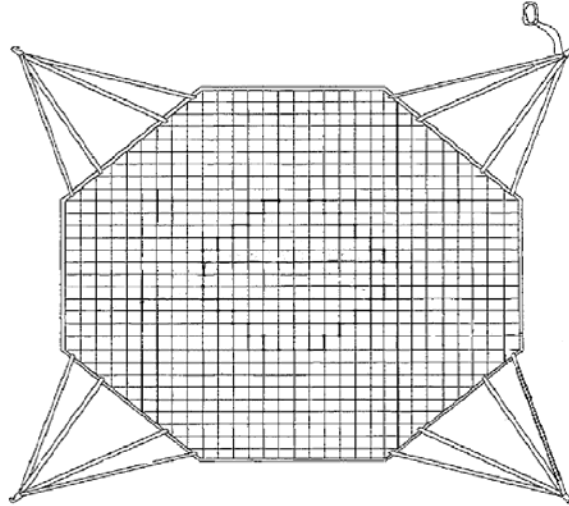
22 April 2015

List of Equipment

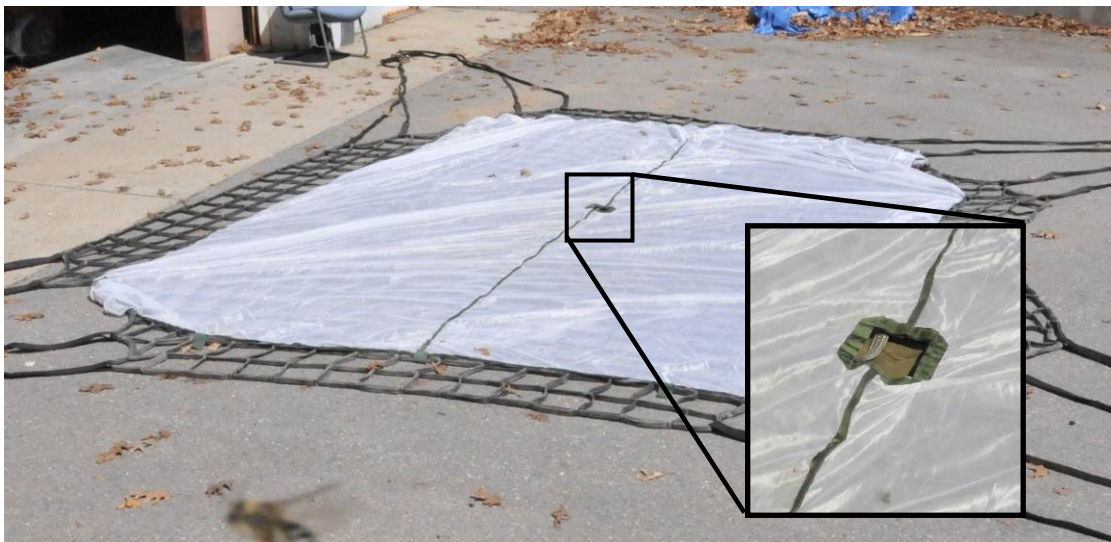
	NSN	PART NUMBER	DESCRIPTION	QTY PER SET
1	4030-01-048-4044	38850-00004-046	Apex Fitting Assembly- Sling	1 ea
2	1670-01-062-6302	68F217-51	2-loop, 20 foot Airdrop Sling	1 ea
3	1670-01-058-3810	6018-10	Net, 10,000-pound capacity	1 ea
			Liner	1 ea
5	8305-00-082-5752	Mil-W-5625	Webbing, nylon, tubular, 1-inch, 4,000-pound minimum breaking strength	4 ea
6		WA-8500-006	Wireless Gate Release	1 ea
7		WA-8000-002	Master Control Station Kit	1 ea
8	7510-00-266-5016		Tape, adhesive, pressure-sensitive, 2-inch wide roll, green	AR
9			Multi-Loop Release	1 ea
10	4020-00-240-2146		Cord, nylon, Type III, 550-pound breaking strength	AR
11	8305-00-268-2411		Webbing, cotton, 1/4-inch, 80-pound breaking strength	AR
12			Aid Item Water Packets	AR

1. Prepare the helicopter sling load (HSL) net.

- a. Lay the HSL net out and identify the center grid square (about 15 grid squares from each edge)



- b. Apply pressure sensitive tape (100 mph tape) around each of the four (4) rope sections that make up the center grid square.
- c. Lay the mesh net liner over the net aligning the center of the net with the center grid square marked with pressure sensitive tape.



- d. Secure the mesh net liner in place by securing the hook and pile (Velcro ®) tabs around the appropriately aligned rope member of the net. Ensure the hook and pile is fully secured.



- e. Slide each of the four (4) leg hooks to as far to the left as possible, folding the hook over the outer suspension line. The hook will rest against the additional webbingkeeper, which restricts the hook movement. Secure the hook to the outer suspension line with two turns of pressure sensitive tape.



- f. Secure the net apex to a convenient location on the outer suspension line of the net with two turns of pressure sensitive tape.



- g. Secure the net inversion lines

1. Cut a section of 1 inch tubular nylon webbing measuring 20 feet long
2. Bend one end of the cut section of tubular webbing 8 inches from the end
3. Tie an overhand knot in the bend of the webbing creating a loop of about 4 inches in length
4. Repeat for the opposite side of the webbing



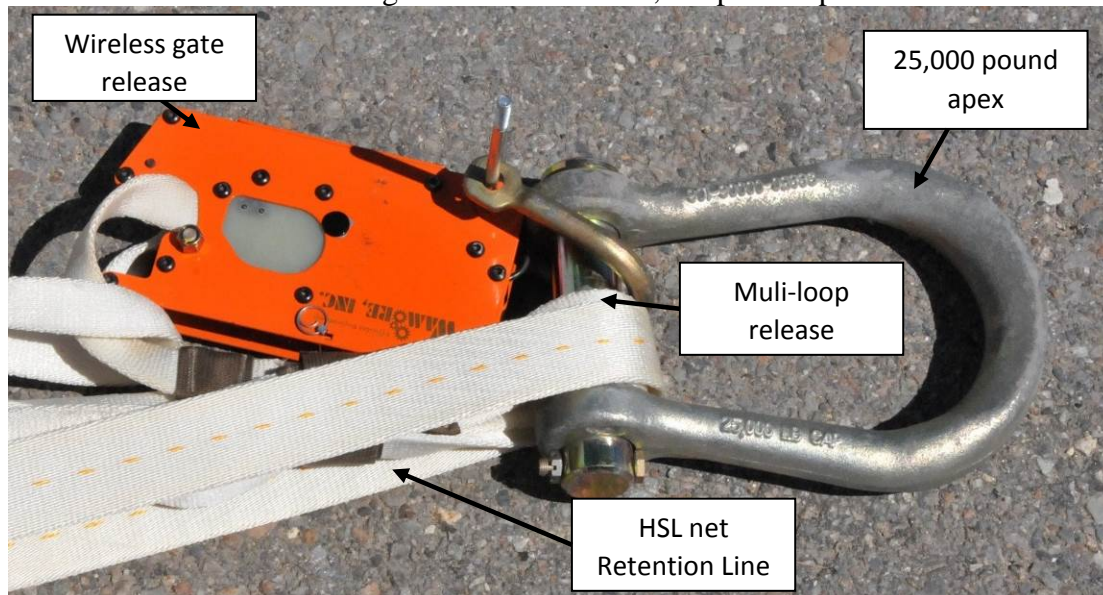
5. Girth hitch one end of the line to the net sling between the securing points of the keeper.



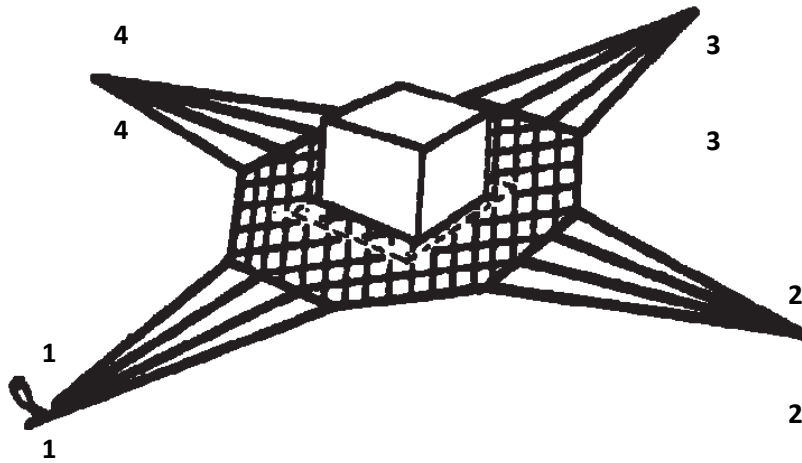
6. Repeat steps 1-6 three additional times until all four (4) net legs have a line attached.
- h. Route all four lines under the net to the center grid square and pass the free ends through the gird square.
 - i. Girth hitch the HSL net retention line through the loop on all four of the net inversion lines.

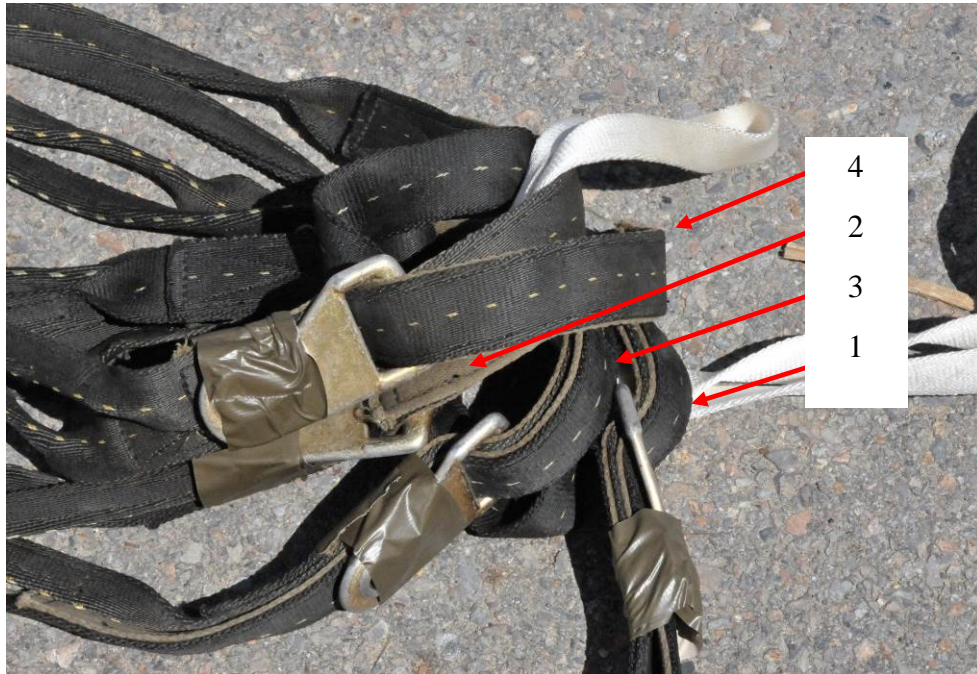


- j. Lay the HSL retention line straight out towards the corner with the HSL apex
2. Place the aid items being delivered into the HSL net, ensuring the HSL retention line runs approximately up the center
3. Attach the system to a 25,000 pound Apex through the following steps:
 - a. Attach the HSL retention line to the 25,000 pound apex.
 - b. Attach the multi-loop release to the 25,000 pound apex.
 - c. Attach the wireless gate release to the 25,000 pound apex via a small clevis?

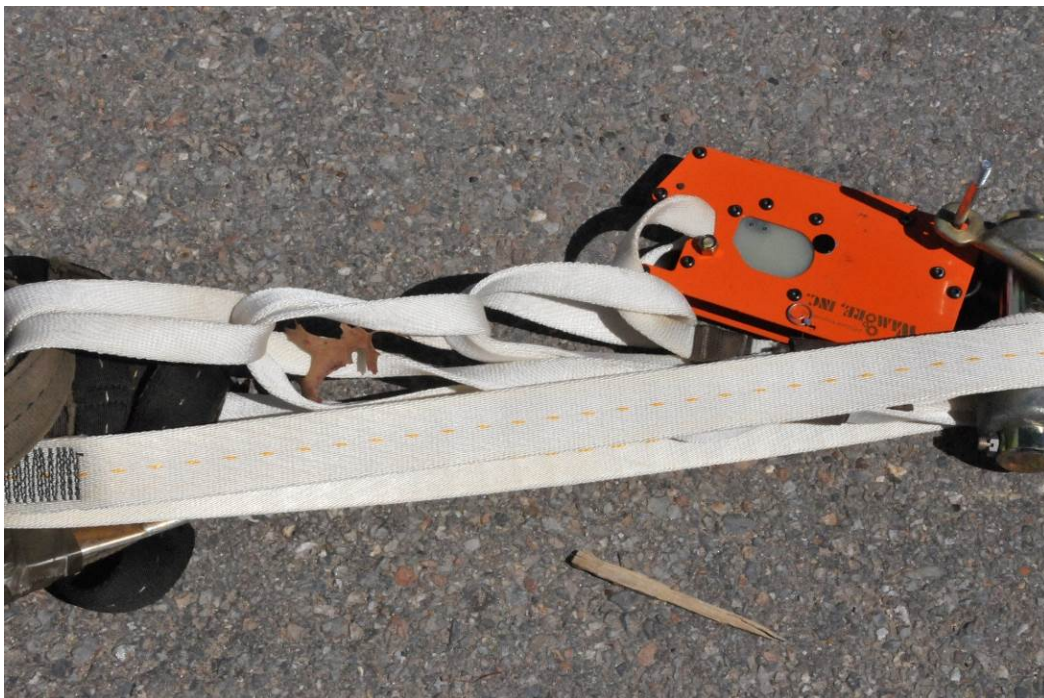


- d. Pass the large loop of the multi-loop release through the net sling leg between the keeper securing points in the following sequence: 1, 3, 2, and 4 to provide equal lift on all legs.





- e. Route the second largest loop of the multi-loop release through the largest loop of the multi-loop release.
- f. Repeat step e for the final two smaller loops.
- g. After routing the smallest loop through, secure it into the wireless gate release.



4. Attach the 25,000 pound HSL apex to the aircraft per TM 4-48.09 Multiservice Helicopter Sling Load: Basic Operations and Equipment